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FUTURE

The sense of touch from cognitive neurosciences to virtual reality



Alberto Gallace & Charles Spence

In Touch with the Future

“Kaleidoscopic in its reach, eclectic in its content, profound in its insight, and above all an evidence-based journey across a touch landscape few will have explored in such breadth and depth, by two cognitive neuroscientists with the perfect pedigree for such an ambitious task. This book will provide an invaluable resource—insights and references—for those researching in or entering the field.”

Francis McGlone, Professor in Cognitive Neuroscience, School of Natural Sciences & Psychology, Liverpool John Moores University, UK

“From the first pages we are convinced that human touch is something we can’t live without: it brings physical and emotional benefits to all of us. Gallace and Spence give an inspiring vision of the future for touch studies. They thoroughly cover issues relating to touch from reality to virtuality, giving us an insight into how touch works and how it can transform our virtual worlds into engaging multisensory experiences.”

Monica Bordegoni, Politecnico di Milano, Italia

“Touch (for neuroscientists the somatosensory system, from receptors to the brain) has been somewhat ‘neglected,’ as compared with the visual system. This is bizarre since our own body is at least as important as our eyes, for getting in touch with objects around us. The book by Alberto Gallace and Charles Spence now fills this lacuna. *In Touch with the Future*, and of course with past research on the neuroscience and psychology of touch, is indispensable reading for neurologists, neuropsychologists and, more generally, for any scientist concerned with how we get in ‘touch’ with the world and the many and diverse objects which populate it.”

Giuseppe Vallar, Professor of Neuropsychology, University of Milano-Bicocca, Italy

“Gallace and Spence manage here to synthesise a monstrous volume of literature into a coherent and informative resource. They write in the way that only true experts can—with clarity, authority, applicability, but no pretence. For some time to come, this will be the definitive resource for anyone interested in the remarkable world of touch.”

Lorimer Moseley, Professor of Clinical Neurosciences, University of South Australia and Neuroscience Research Australia

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Section A

Touch in the laboratory 1: Introducing the sense of touch

Chapter 1

Introduction

1.1 The world of touch

1.1.1 Touch makes real

What is real? Is a beautiful sunset real? Or the melt water in a beautiful mountain lake? When we see something amazing, unexpected, or just plain surprising, aren't we sometimes puzzled about its very "reality?" And what do we normally do in order to convince ourselves of its actual existence outside the realms of our own mind (or imagination)? That's right, whenever possible we touch it. In the bible, Saint Thomas is said to have put his fingers into the chest of Jesus in order to be sure that he really had been resurrected (see Figure 1.1). Touch, then, is often depicted as the sense that cannot be deceived or fooled. It is the sense that makes the world real to us! In fact, until recently it was widely (albeit incorrectly; see Ernst & Banks, 2002; Rock & Victor, 1964; Gori, Del Viva, Sandini, & Burr, 2008) believed that "touch educates vision," and that visual perception, being grossly different from the image that first falls onto the retina, must be acquired as a result of tactual experience (e.g., Gregory, 1967).

The surface of the human body, the skin, is actually one huge sheet of tactile receptors. It provides us with the means to connect with our surroundings. Despite the importance of vision to our everyday lives, it is the skin that constitutes both the oldest and by far the largest of our sense organs (e.g., Field, 2001; Montagu, 1971). The skin protects our body from the external world and, at the same time, it informs us about what occurs on its surface.

We never doubt the reality of a kiss, a caress, a hug, or a handshake. These are amongst the most common of the human species' social activities. We may sometimes be uncertain about their meaning, but rarely do we doubt their very occurrence. These forms of social tactile interaction accompany us from childhood through adulthood and into old age. In fact, tactile sensations are the very first to develop, given that a 6-week-old fetus (although completely blind and deaf) is already able to react to tactile stimuli (e.g., Atkinson & Braddick, 1982; Bernhardt, 1987; Bremner, Lewkowicz, & Spence, 2012; see also Fitzgerald & Gibson, 1984). What is more, these sensations can carry an incredible emotional punch (see Field, 2001). Such interactions, other than being very real and immediate, might appear simple, and natural. But that apparent simplicity belies a degree of complexity that researchers have only recently started to investigate with the requisite vigor. How, then, can someone even dare to mechanically reproduce that complex mixture of sensations delivered to the body surface? And what actually needs to be reproduced anyway? How can we make people feel these sensations as "real" when, in fact, they have been reproduced artificially (mechanically)? And what differences are there between reproducing the sensory aspects of these experiences and reproducing their hedonic value (or valence)? That is, we are all used to kissing and/or hugging, we know what these acts are like, and how it feels for someone to touch us. We even know (or at least most of us do) when and where it is appropriate to engage in, or to avoid, any such important social contacts. What we don't know is what pattern



Fig. 1.1 *The Incredulity of Saint Thomas*, 1602–1603 (oil on canvas), Caravaggio, Michelangelo Merisi da (1571–1610) / Schloss Sanssouci, Potsdam, Brandenburg, Germany / Alinari / The Bridgeman Art Library.

of neural stimulation actually gives rise to the sensation of a “kiss” or of a “hug.” What receptors need to fire, and which brain areas need to light up?

In fact, as we will see later, we currently know surprisingly little about the machinery underlying human social interactions that involve the sense of touch. Consequently, the challenge of reproducing these sensations artificially might seem utterly impossible. Moreover, this process is made all the more complicated by the fact that tactile interactions rarely (if ever) occur in isolation, that is, in the absence of visual, auditory, and/or olfactory stimulation. Thus, the meaning, not to mention the hedonic value of a tactile interaction, may vary as a function of the presence (versus absence) of other multisensory cues. Being caressed by one’s spouse is certainly very different from being involuntary nudged by a stranger’s bag while traveling on the underground, say. This difference persists despite the possibility that a similar activation of the tactile receptors may have given rise to both sensations. That is, the meaning of touch is something that goes far beyond the stimulation of the skin surface and this is why our experience of it is affected by our beliefs, or expectations (be they right or wrong), regarding who it is who is doing the touching, and why. If you are a heterosexual male and you have reason to believe that the tactile stimulation on your legs comes from an attractive lady, then your perception of that touch will undoubtedly be very different (in terms of the neural activity elicited by the touch itself) than that elicited if one thinks that the touch came from a brusque man wearing a tracksuit instead (see Kress et al., 2012).

Besides the more intuitive (at least to the naïve observer) domain of social interactions, the more perceptual (or sensory discriminative) aspects of touch are also immensely important for our everyday lives. One may think, for example, of the feel of velvet against the skin, the friction of a knife against a patient’s internal organs for the surgeon, that stomach-churning shake of turbulence we sometimes experience while flying, the bump on the street for the driver of an automobile, the feel of a swollen gland for a physician, the feeling of a thousand-year-old human artifact for a museum curator, and so on. Certain of the activities that touch contributes to are performed with intent, many others, probably the majority, take place automatically, often leaving

us completely unaware of their very occurrence (that is, we are unaware of the majority of what is going on at the skin's surface). This is perhaps the reason why people often underestimate the importance of touch to their everyday lives. Even apparently common activities such as walking around, finding the gear in a manual-transmission car, playing a musical instrument, eating, or picking up an object, all require a great deal of haptic¹ information processing.

Speaking and chewing were almost impossible, and for several months she existed solely on pureed food. Then she became so exasperated by this that she began to experiment in eating. She learned to push food to one side of the mouth, chew a certain number of times, and then push the food to the back of her mouth and swallow it automatically. Facial expression was severely limited because of the absence of proprioception from the lower face. She refused to look in a mirror for two years after the illness. For a similar time, she had to remember to concentrate to keep her mouth from opening. (Cole & Paillard, 1995, p. 249)

As this quote, taken from the description of a patient, so poignantly suggests, those individuals who lack basic tactile sensations, not to mention, proprioception (for example, as a consequence of brain damage or peripheral nerve damage; see Cole, 1991), abilities that the rest of us take for granted, experience profound difficulties when it comes to controlling their movements; even something as simple as holding a fork and bringing it to one's own mouth becomes a veritable challenge (e.g., Cole, 1991; Cole & Paillard, 1995).

Walking without touch can be problematic too. The tactile receptors on the soles of our feet provide us (or rather, our brains) with a constant source of information about the characteristics of the surfaces that we happen to be walking on; that is, whether it remains constant, such as when we stand waiting at the bus-stop, or whether it changes continuously, such as on the deck of a boat out sailing on a choppy sea. This information is constantly integrated with vestibular cues regarding the position of our body in three-dimensional (3D) space. As a consequence, our brains are continuously informed about whether we are walking on carpet or tiles, sand or wood, mud or gravel, on a slope versus on a flat surface, and reacts as a consequence by changing the way in which we proceed.² This all happens every second of our waking life and regardless of whether we are aware of it or not. Despite our frequent apparent lack of awareness, these sensations are nevertheless well known and have also entered into our daily vocabulary. Think, for example, of

¹ Many researchers think it important to distinguish haptic from tactile perception because the former involves the active, serial exploration of a stimulus. It also involves the movement of different parts of the body. Loomis and Lederman (1986) proposed an extended classification of tactile sensation that distinguishes between five different “modes of touch” as a function of the presence versus absence of voluntary movement: (1) tactile (cutaneous) perception, (2) passive kinesthetic perception (kinesthetic afferents respond without voluntary movement), (3) passive haptic perception (cutaneous and kinesthetic afferents respond without voluntary movement), (4) active kinesthetic perception, and (5) active haptic perception (see also Klatzky & Lederman, 2002). This classificatory scheme highlights the fact that at least one additional form of stimulation, namely kinesthesia, also contributes to our perception of actively explored stimuli. Given that what is commonly referred to as the sense of touch actually appears to encompass several distinct sensory systems (e.g., cutaneous, kinesthetic, and haptic; Klatzky & Lederman, 2002), it should perhaps be considered more of a multisensory (i.e., derived from the integration of different sensory inputs) rather than a single sensory modality.

² Note that patients, such as those previously described, who lose their ability to process proprioceptive and tactile information cannot even stand or walk should the lights go off (see Cole, 1991; Cole & Paillard, 1995).

the expression “walking on eggshells” (or “walking on broken glass,” the phrase celebrated in the title of one of Annie Lennox’s most famous pop songs). The effectiveness and immediacy of these expressions are probably related to an automatic link with tactile sensations.

Surprisingly, even vision, the most intensively investigated of the senses, and the one that most of the time seems to dominate the mental lives of sighted individuals (not to mention researchers), is often affected by touch. In particular, it has recently been demonstrated that the shape of an object held in our hands can affect our ability to find similarly shaped items in a visually cluttered scene (List, Iordanescu, Grabowecky, & Suzuki, 2012). That is, whenever we can’t find our car keys or mobile phone, perhaps we should simply grab someone else’s and keep it/them in our hands while searching. Bizarre though it sounds, it just might help. In fact, over the last decade or so, researchers have consistently reported that tactile information as well as information regarding the current position of our hands in space can affect our ability to direct visual attention toward the stimuli around us (e.g., Abrams, Davoli, Du, Knapp, & Paull, 2008; Reed, Betz, Garza, & Roberts, 2010; Reed, Grubb, Betz, & Baker, 2004; Reed, Grubb, & Steele, 2006; Spence et al., 2008).

If you still remain unconvinced of the importance of touch then just try lying down for a few seconds with your eyes closed. If you concentrate, you should soon be able to feel the distinct perception of your body, as a separate entity from the surface on which you happen to be resting. There you are, and there is the surface on which you are lying, just out there, so close to our skin and still so different from it. That is, one additional and perhaps even more important role for the sense of touch (and likely the first to have evolved in the animal kingdom) is to set the boundaries of the self (e.g., Moseley, Gallace, & Spence, 2012a). That is, the sense of touch plays a major role in terms of contributing to differentiating ourselves from the external world; “Where touch begins, we are” (or at least, we “perceive” ourselves to be), if one can put it that way.

It is also important to note that when it comes to the world of touch, just as for other aspects of our everyday experiences, we are not all the same. For example, there are some people who like to engage in tactile contact more than others (as measured by the “need for touch” scale; Peck & Childers, 2003a, 2003b; see Chapter 11). Similarly, people also differ in terms of their perception of what constitutes the optimal ambient temperature (e.g., Blankenburg, Meyer, Hirschfeld, Kraemer, Hechler, Aksu, Krumova, Magerl, Maier, & Zernikow, 2011; Green & Akirav, 2007), in terms of their susceptibility to a variety of tactile illusions (e.g., Durgin, Evans, Dunphy, Klostermann, & Simmons, 2007; Haans, Kaiser, Bouwhuis, & IJsselstein, 2012), in their ability to direct their attention to, or concentrate on, tactile stimuli (e.g., Brown, Poliakoff, & Kirkman, 2007; cf. Schaefer, Heinze, & Rotte, 2012a), etc. All of these factors need to be considered if one’s aim is, for example, to try to develop new products that have been customized for the tactile preferences of different classes of users (consumers).

As has been mentioned already, the skin alone protects and physically differentiates our body from the outside world (note, however, that touch also contributes to maintaining the integrity of the skin; see Iggo, 1977), but it is our sense of touch, working in tandem with the other senses, that contributes to making this difference possible at the psychological level. The philosopher Mark Taylor (1997, p. 13) nicely summarized this concept as follows: “At the point where I make contact with the world, I am always already dead.” Of course, these observations have important theoretical and practical implications (e.g., related to the relationship between mind and body, or to the possibility to create artificial tactile sensations even without the presence of the body). It also leads to some surprisingly tricky questions: So, for example, if one starts to feel touch in a part of space that is different from where one’s own body (or a part of it)

actually happens to be, will one really “feel” it to be there? And under what conditions, if it is even possible at all, can a person experience touch away from the tactile receptors located in his/her skin? Responding to these apparently trivial questions turns out to be of great importance if one considers the situations that can now be delivered by means of virtual reality (VR) technologies. We might think, for example, about tele- (or remote) surgery, a technique that, now more than ever before, is enabling surgeons around the world to operate using haptic interfaces that control robotic systems located at different locations. In fact, the first operation using this kind of technology was conducted in 2001 by a surgeon in New York, performing an operation on a patient located more than 6000 km away in France (see Marescaux, Leroy, Gagner, Rubino, Mutter, Vix, Butner, & Smith, 2001).

The last few years have seen a dramatic increase in the popularity of “virtual worlds.” These computer-generated environments now allow for totally new forms of long-distance human interactions to occur in cyberspace (see, for example, the increasing popularity of *Second Life* by Linden Lab; Wagner, 2008; see also the fantasy game *World of Warcraft* by Blizzard Entertainment). It has been suggested that this trend toward virtual interactions is set to increase in the years to come. However, advances in tactile and haptic interaction technologies within these environments will be required if this trend is really to continue its phenomenal growth. Indeed, in 2007, analysts estimated that up to 80% of active Internet users (and 500 businesses) would have a “second life” in a virtual world by the end of 2011 (see Gartner Inc., 2007). This prediction, like many others concerning the future of touch, doesn’t seem to have been fulfilled. This negative outcome might also be related to the slow diffusion of haptic devices amongst the ever-growing population of Internet users out there. One might, then, wonder whether predictions such as these will ever be fulfilled. A cursory reading of the literature soon reveals that the promise that tactile interfaces were soon going to radically change our lives is rather widespread. However, the majority of the predictions concerning the use of touch on our everyday lives simply haven’t come to pass. Take, for example, claims regarding the imminent arrival of “tactile television” (see Collins, 1970), a device that, writing more than 40 years later, has still to be invented, never mind popularized. Similarly, those working in the stock market would be equally curious if one was to tell them that researchers in the 1960s had predicted the imminent arrival of the vibrating belt that was supposed to silently provide up-to-date information about the status of the stock market (e.g., Hennessy, 1966). And couples probably won’t come across t-shirts that are capable of transmitting their hugs through cyberspace or via a mobile device (see Chapter 7) for a few more years yet (see Chapter 9). By contrast, other devices such as haptically controlled and/or enabled mobile phones and touch screens mostly lay in our pockets or on our desks.³ So what does the future hold in terms of the stimulation of the sense of touch? To what extent will the rapidly developing tactile technologies become an increasingly important part of our lives?

Recently, we have seen the appearance of new technologies that are capable of eliciting believable sensory stimulation (simulations that can be perceived as “real”) at a much more reasonable price than ever before (see Stone, 1992; see also Gallace, Tan, & Spence, 2007a, for a review). Led by such advances, VR technologies might, for the first time in human history, soon be capable of creating the opportunity to locate and control a virtual counterpart of our own body (or even

³ If you are the parent of a small child, you will probably have noticed that many toys nowadays make increased use of tactile stimulation. For example, toy guns no longer just make sounds and flash but are now equipped with vibrating devices such as those found in mobile phones—devices that add tactile feedback to the overall multisensory playing experience.

artificial additional prostheses of it; see the concept of teledildonics, e.g., Machulis, 2006) in places that are far removed from the actual position where our own body happens to be (and even to do so in more than one location at the very same time; a “gift” of such an importance that in the ancient literature only Gods were meant to have; Oden, 1992). The sense of touch, being thought of as the most important in terms of making our experiences “real” (see Berkeley, 1732), will certainly assume a leading role in this context.

In order to clarify this point, it is possible to think about one’s personal experience as a tourist. What exactly is the difference between seeing the photos or even watching a video of one’s holiday (or worse still someone else’s), flicking through a holiday catalogue, and actually “being” on holiday in the Mediterranean? Is it the feel of the hot sand on our feet? The fresh water and the warmth of the sun on our skin? The gentle sea breeze rustling through your hair? All of these tactile sensations contribute in a fundamental way to making for that memorable holiday experience. In fact, visual images sometimes require us to think about their tactile counterpart in order to be fully appreciated. This is how Bishop Berkeley put the concept nearly three centuries ago: “Visible figures are the marks of tangible figures; and . . . it is plain that in themselves they are little regarded on upon any score than for their connection with tangible figures, which by nature they are ordained to signify.”⁴

However, as far as the idea of reproducing believable tactile sensations in virtual or mediated environments is concerned, many fundamental questions still remain to be answered. For example, one might wonder whether people interacting in a multisensory virtual world will “automatically” and “effortlessly” perceive tactile sensations as arising from their “Internet avatar” (wherever that avatar appears to be located), or whether instead they will attribute tactile stimuli to it only as a consequence of an explicit (and time-consuming) cognitive effort. Whether or not the perception of a “digital self” (e.g., Hicks & Kennedy, 2010) somewhere in cyberspace will ever be possible also seems to depend on our ability to fill in the gaps in our scientific knowledge regarding the sense of touch. It might be interesting to note here that the very possibility of creating the illusion that a human operator is present in a remote environment, or else is fully immersed within a computer-generated world, has been defined as the “Holy Grail” of VR and research on haptic devices (Stone, 1992). This possibility has only just started to be fully tested in the last 5 years or so, thanks in no small part to the insights that have been emerging from the extant cognitive neuroscience research (e.g., Ehrsson, 2007; Lenggenghager, Tadi, Metzinger, & Blanke, 2007).

Another important point related to the possibility of reproducing believable tactile sensations in virtual or mediated environments lies in the role of “pain.”⁵ Certainly, a number of real interactions can never be entirely believable without the presence of painful stimulation. However, one might wonder whether reproducing such kinds of stimulation would ever be of any use within virtual or mediated interactions. Shouldn’t a “virtual” world be, in some sense, “better” without

⁴ Note that according to the philosopher and theologian Thomas Aquinas (1958), the fundamental basis for the “sensus communis” (the perceptual power of binding the inputs from the individual sense organs into a coherent and intelligible representation) is to be found in the sense of touch . . . “[Touch] is the first and in a way the root and foundation of all senses . . . This power is attributed to the sense of touch not as a proper sense, but because it is the foundation of all senses and the closest to the frontal root of all senses, which is common sense.”

⁵ The question of whether or not pain and touch should be considerate separate sensory modalities continues to be debated by philosophers and scientists alike (see Auvray, Myin, & Spence, 2010, on this point).

pain? Even if not immediately intuitive, there are a (admittedly small) number of situations in which the ability to deliver painful stimulation comes in handy within mediated environments. In fact, numerous attempts have been made over the course of the last few years to reproduce these aspects of our perception as well. This may occur in videogames to increase the realism of the simulation or even more importantly in training programs for soldiers where pain is an occupational hazard and will need to be dealt with.

Perhaps, in the future, we won't need to inspect our pockets haptically in search of the car keys. Indeed, most of our activities will likely be performed from the comfort of our own homes without even the need for a vehicle. However, we believe that all of this will occur only if touch becomes an integral part of our communication technologies. As yet, few of these technologies are part of our everyday lives. For example, one may think of the vibrations that inform us of the mobile phone ringing in our pocket (e.g., see also Brown & Kaaresoja, 2006) or the recently introduced vibrating seats and seatbelts installed in certain models of car, which now inform the driver of any unintended lane crossing (see "Lane departure warnings," 2005; see also Chapter 10). As a matter of fact, a growing number of tactile devices will likely come to be a part of many of our lives that we simply take for granted in the years to come. They will also change the way in which our brain processes and selects information from the outside world (that is, sensations that were once considered of little relevance, such as random vibrations, will likely be prioritized and even hallucinated by the neural circuits in our brains; see, for example, the phantom vibrations coming from our mobile phones; e.g., Baillie, 2011; see Chapter 2, on this topic). One of the main aims of this book, then, is to help to make these possibilities more likely by bringing together the knowledge that has emerged from cognitive neuroscience research on tactile and haptic information processing in recent years and the need for new forms of long-distance interactions and human-machine interfaces. This should make it possible to really exploit the power of touch. Currently, the sense of touch is a relatively underused channel of mediate communication (meaning that it involves virtual or human-machine interfaces). Besides the domain of virtual interactions, real interactions will likely also benefit from a better understanding of the ways in which our brains process and integrate the information from the tactile receptors in the skin itself. Here one might think, for example, of the need to design and produce objects that are more appealing to the sense of touch (see Chapter 11). Indeed, according to the results of one survey, 35% of consumers consider the feel of a mobile phone as being more important than its look ("Does it make sense?," 2007). Considering the emotional impact that tactile sensations can have on our daily lives, it is not so surprising to observe that designers and marketers are becoming increasingly aware of the importance of exploiting the tactile modality as a successful means of enhancing sales (see Spence & Gallace, 2011; Spence & Piqueras-Fiszman, 2012). It now seems certain that the future will deliver more and more products that have been designed specifically to stimulate our non-visual senses, and tactile stimulation will constitute a key component in this multisensory onslaught (be it the enhanced feeling of softness, or perhaps the simulated feel of naturalness).

Finally, it has been argued for a number of years now that our society is becoming increasingly "touch hungry" because of the reduction in social tactile interactions (e.g., Field, 2001, 2004; see also Spence, 2002b). The elderly population (as well as those suffering from limited mobility) are probably the ones to suffer the most from this condition (e.g., Nelson, 2006; cf. Stevens, 1992; see also Dias, Pires, Pinto, Teixeira, & Freitas, 2012). A better understanding of the sense of touch, and of the ways in which stimulating (and simulating) it more effectively in order to improve our well-being and the quality of our life should hopefully avoid our society from ending up like the grotesque one described in the 1990s science fiction movie *Demolition Man* (starring Sylvester

Stallone, Wesley Snipes, and Sandra Bullock), where any kind of physical contact was prevented and heavily sanctioned! The lack of touch can lead to profoundly negative consequences. This fact was initially highlighted by the controversial and pioneering studies by Harry Harlow on baby monkeys (see Chapter 7).

1.2 A brief story of tactile research

Over the last decade or so, there has been a growing wave of academic interest in the study of the sense of touch, resulting in the publication of a substantial body of research (e.g., see Gallace & Spence, 2008a, 2008b, 2011; Gallace, Tan, & Spence, 2007a; Spence & Gallace, 2011, for reviews) and a good number of edited books as well (e.g., Chatterjee, 2008; Classen, 2012; Field, 2001; Gescheider, Wright, & Verrillo, 2009; Hertenstein & Weiss, 2011; Knoblich, Thornton, Grosjean, & Shiffrar, 2006; Pye, 2007; Zadeh, 2010). Why has this happened? What was so special over the last few years to justify such a growth of interest in this particular topic (sensory modality)? It might be worth noting here that research on tactile information processing has actually never witnessed entirely quiet periods since its very beginning, but rather a steady growth of interest over the years (see Figure 1.2). During the 1960s, there was an explosion of interest in the study of touch. This initial spurt of interest was likely driven by a number of different factors. In particular, the introduction of new tactile technologies and the insights derived from the extant research on the physiology of touch in those years made it possible to artificially stimulate (in a reasonably well-controlled manner), a number of different classes of tactile receptors across the body surface (e.g., initially by means of electrocutaneous stimulation; see R. H. Gibson, 1968). This created the appropriate conditions for the development of the first human-machine interfaces. The strategic importance of providing information “silently” and perhaps even more reliably

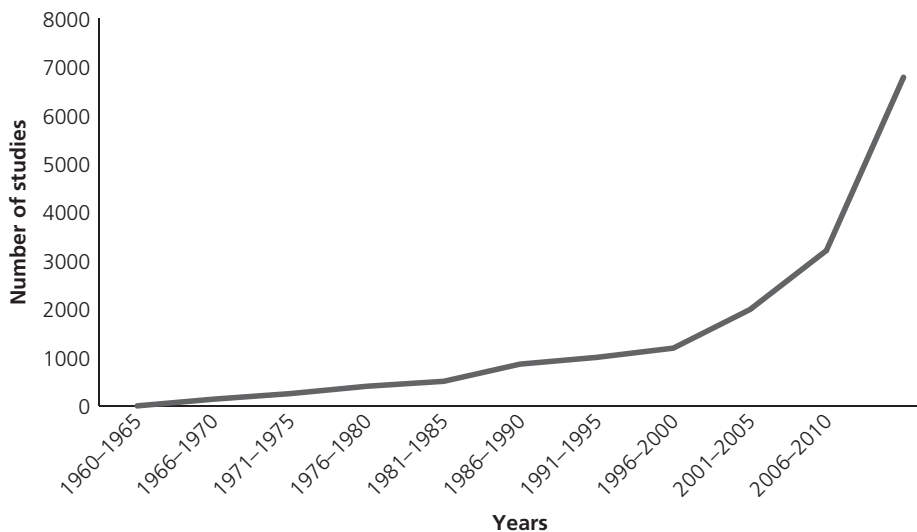


Fig. 1.2 Number of studies on touch published from 1960 to 2010. Search performed on October 10, 2012 on Scopus, using the terms “touch” or “tactile” or “haptic” in the title. Note that from January 2011 to October 2012 alone, 2874 studies were published (nearly half of the number published in the preceding 5 years). If this trend continues, then there may well be in excess of 10,000 published studies on touch by 2015.

(when compared with certain conditions of stimulation where vision or audition are overloaded) to human operators via the skin surface certainly couldn't pass unobserved by the military or by a range of civilian industries.

Indeed, one of the first academic conferences to be held on the topic of touch and haptics took place at Fort Knox, USA, where, in 1960, a group of investigators gathered together to discuss the basic problems associated with any attempt to communicate by means of the skin surface (for a summary of this workshop, see Hawkes, 1960). In the 1970s, research interest was also drawn toward the possibility of providing visual information to blind individuals by means of stimulating their skin with arrays of tactile stimulators. The first tactile visual substitution systems (TVSS) were developed rapidly and soon tested (e.g., Geldard, 1960; R. H. Gibson, 1968; Hennessy, 1966; Von Haller Gilmer, 1960, 1961; see Chapter 9). These new devices allowed for visual information to be “translated” into patterns of tactile stimulation presented on particular regions of the skin surface (e.g., on the back; see Bach-y-Rita, 1972).

Despite the unprecedented research efforts and economical resources that have been devoted to the study of the tactile modality, the practical applications that resulted from those early scientific insights have proven to be surprisingly thin on the ground (see Gallace et al., 2007a, for a review). We would argue that this surprising lack of applied success might, in part, be related to the failure of the majority of early research studies to consider the central/cognitive as well as the peripheral limitations that may constrain tactile information processing (see Gallace et al., 2007a). Moreover, one should also consider that all of the limitations of touch discovered under conditions of unisensory stimulation, when only tactile stimuli are presented within an ideally (at least from the point of view of the experimenter) dark and “sterile” experimental testing environment, are likely unfit to capture (or provide a good model for) what actually occurs in the real “world of touch,” where our senses are literally bombarded by concurrently presented multisensory stimuli.

As mentioned already in this chapter, early research on the sense of touch (just as for more recent work) has never been unproductive in terms of outlining many of the potential advantages of exploiting the tactile sense; these have ranged from developing tactile television for the blind (Collins, 1970), to having stock market traders reading the latest company figures at 60 words per minute by means of a vibrating tactile belt around their waists (Hennessy, 1966). Even the exciting promise that we could all acquire a new sense (the position sense) from a tactile belt stimulating the direction of North has been made (e.g., Nagel, Carl, Kringe, Martin, & König 2005; see also Chapter 9). But, one might reasonably ask, how have these various attempts and promises to fill the future with touch survived over the years?

In the chapters that follow, we will try to describe many of the technologies that have, in the last years, been proposed, in order to understand the reasons for the success of a minority of them, and the failure of the majority of them. We hope to convince the reader that, if anything, what a review of 50 years of research and unfulfilled predictions leads to is a skeptical view regarding any claims concerning the “imminent” adaptation of tactile technologies in some or other area of our everyday lives (especially in those domains where the empirical research has the largest gaps to fill).

On the basis of the earlier-mentioned considerations, one might therefore wonder why the new wave of interest that has been witnessed over the last decade or so should lead to results that are any more successful in the future. As far as this point is concerned, a number of factors need to be taken into account. In particular, empirical research has now reached a much greater state of development concerning the functioning of the sense of touch than in the past. Specifically, scientific knowledge has now spread to cover most of the aspects of tactile information processing that were hardly investigated in previous research, such as our memory for touch, our awareness

and consciousness of touch, our attention to touch, and the neurological substrates of our tactile perception (although, it must be admitted, still in a much reduced fashion as compared to the study of these phenomena in the other sensory modalities). It is also worth noting at this point that research over the last few years has been conducted in order to investigate the more central (i.e., cognitive) and emotional aspects of tactile information processing, as well as the more peripheral factors (i.e., such as, for example, tactile sensitivity differences across the skin surface; e.g., Weinstein, 1968; see also Gemperle, Hirsch, Goode, Pearce, Siewiorek, & Smailigic, 2003) affecting our perception of touch. Interestingly, this new wave of research interest has already provided some intriguing insights.

In particular, while the presence of different classes of tactile receptors in the skin has been known about for decades, it is only recently that researchers have discovered neural fibers, not to mention brain areas, that appear to respond specifically to pleasant tactile sensations (such as the feeling associated with stroking velvet over the skin; see Chapters 2 and 7). These results, together with others showing that tactile contact mediates the release of oxytocin (a hormone that is related to “bonding” behavior; Bartels & Zeki, 2004; Insel & Young, 2001; Walum, Lichtenstein, Neiderhiser, Reiss, Ganiban, Spotts, Pedersen, Anckarsäter, Larsson, & Westberg, 2012), certainly open up a variety of exciting new possibilities for the future use of tactile stimulation within a number of different contexts (from the treatment of autism to virtual social networking; e.g., Shabani, Katz, Wilder, Beauchamp, Taylor, & Fischer, 2002). There are now increasing signs that these especially interesting aspects of the sense of touch can (and in some cases already are) be exploited in order to improve the quality of life of many of us. Certainly, it is no longer surprising to find coin-operated massage chairs or even actual masseurs and masseuses in airports or waiting areas (or increasingly, even out there on the street). Similarly, an increasing number of the goods that can be found in executive stores (e.g., such as The Sharper Image in North America) appear to have been explicitly designed to stimulate our sense of touch (see Spence, 2002b).

Another important factor that also contributes to differentiating previous research from that conducted more recently is the widespread interest in the study of multisensory information processing (e.g., see Bremner et al., 2012; Calvert, Stein, & Spence, 2004; Spence & Driver, 2004; Stein, 2012). In particular, while the majority of researchers previously concentrated on studying only a single sensory modality at a given time (e.g., see Barlow & Mollon, 1982), researchers are now interested (perhaps more than ever before) in the study of the interactions between stimuli concurrently presented to different sensory modalities (Stein et al., 2010). This approach represents a great advance from both a theoretical and applied perspective but, at the same time, it also makes the study of sensory perception more complicated than it already was.

Over the last decade or so, multisensory research has demonstrated that while important differences are present between information processing in the different sensory modalities, certain stages of information processing, such as those contributing to maintaining and updating the representation of space, or those thought to direct attention toward particular aspects of external objects/stimuli, might actually be shared between different sensory modalities (e.g., Downar, Crawley, Mikulis, & Davis, 2000; Ho & Spence, 2008; Spence & Driver, 2004; Spence & Gallace, 2007). More generally, the majority of researchers currently believe that multisensory integration is vital for any organism wishing to develop a sense of “spatial perception.” In addition, scientists have demonstrated that the limitations that affect human information processing when stimuli are presented from just a single sensory modality might be dramatically different from those that affect information processing under conditions of multisensory stimulus presentation (e.g., Gallace et al., 2007b). Finally, it turns out that the congruency and redundancy between information presented from different sensory modalities may lead to an improvement in participants’

performance in a variety of different tasks (Chen & Spence, 2010, 2011; Ernst, 2007; Ernst & Banks, 2002; Ernst & Bühlhoff, 2004; Spence, 2011b, 2011d). Note, however, that the ability to correctly integrate different sensory modalities takes time to develop and that, for example, the integration of visual and haptic spatial information turns out to be far from optimal until around 8 years of age (e.g., Gori, et al., 2008; Streri, 2012; see also Bremner, Holmes, & Spence, 2008; Bremner, Mareschal, Lloyd-Fox, & Spence, 2008; Bremner et al., 2012; Cowie, Makin, & Bremner, 2013).

Here it is also worth noting that multisensory conditions of stimulus presentation offer a much more ecologically valid situation as compared to the unisensory conditions of stimulation that characterize so many of the studies published in the past (but also more recently). Indeed, one may easily note that in our everyday lives performance is affected and driven by various different combinations of visual, auditory, tactile, gustatory, and olfactory stimuli that happen to stimulate our various sensory receptors at any given time. Certainly, if one's aim is to reproduce veridical environments in a virtual world, or else to create an interface-mediated simulation of a given situation, the study of multisensory information processing and crossmodal interactions between different modalities of stimulation becomes vitally important. As far as this point is concerned, it is worth noting that Stone (1992, p. 7), in a review of the literature on haptic feedback systems, wrote more than 20 years ago now that: "it is not the visual modality per se that won the race to deliver this interface [the truly intuitive interface], but the combined senses of vision, force and touch." An interesting anecdote might help to clarify what we see as the main concept here.

A few years ago, a multimillion-dollar driving simulator was built in one of the world's leading academic research facilities. However, despite the immense amount of technological and economical resources devoted to its development (mainly spent on ensuring a supremely high-quality visual display), the first test runs with the simulator did not give rise to the expected sense of presence from its users that had been hoped for. That is, people did not really have the feeling that they were "driving." Eventually, though, someone had the bright idea of adding a battery powered fan whose speed of operation was controlled by the speed of the simulated movement. That cheap plastic fan controlled by the speed of the simulated driving made all the difference in terms of enhancing the user's sense of presence. Once the users of the device felt the air blowing onto their face while "driving" the simulator, they really started to feel as though they were driving (i.e., the sense of presence was enhanced)!⁶

As the anecdotal example just described illustrates so nicely, the wise use of visual and tactile stimulation devices can make a huge difference to a virtual counterpart of a real situation. Moreover, this example also highlights the fact that we sometimes don't need to simulate very complex stimuli in order to obtain the immersive experiences that we are searching for. That is, often finding a simple stimulus that can capture the user's attention will suffice in terms of enhancing the overall sense of presence within a given multisensory environment. In fact, since we typically only pay attention to a small part of our environment, there is little point in accurately (not to mention expensively) simulating what falls outside of the focus of our attention. In other words, if we know what people are going to attend to, or what kind of stimuli naturally pop-out from their backgrounds, we also know what one needs to simulate with high fidelity (leaving all the rest to lower-resolution representations that perhaps capture nothing more than the "gist" of a

⁶ Something that Morton Heilig (1962) figured out a few decades ago with his "Sensorama machine" (see Chapter 9), where a fan was used to simulate the air flow in a simulated motorcycle drive.

scene). Understanding the way in which our brains process and integrate tactile information can lead not only to the development of better and more efficient environments/interfaces but also to avoiding the unnecessary waste of both economical and professional resources.

One factor that has probably adversely affected the development of tactile mediated/virtual interactions in the past is that the bandwidth of touch is lower than that of the other senses (e.g., Gallace, Ngo, Sulaitis, & Spence, 2012). That is, the amount of information that the tactile channel carries is much lower than that potentially carried by either vision or audition (see Table 1.1). In addition to the fact that this claim is, anyway, debatable (see Gallace et al., 2012), it should be considered that the overall amount of information available does not necessarily always relate to its value or importance to an organism. That is, the power of the tactile channel to transmit emotional (and sometimes vitally relevant) information can certainly overpower its bandwidth limitations (e.g., Ho & Spence, 2013). This is how Albert Einstein once described the emotional power of interpersonal touch: “Any man who can drive safely while kissing a pretty girl is simply not giving the kiss the attention it deserves.”

There is another factor that emerges from the scientific research and that would seem to lead to a more positive and proficient outcome for the current study of the sense of touch. This is related to the recent interest in the mechanisms underlying our brain’s ability to sustain neural representations of the body. Indeed, while the concept of “body representation” has been present in the cognitive neuroscience literature for a number of years now, alternative methodological and theoretical approaches (for example, by using prosthetic limbs, crossmodal stimulation, and VR technologies; e.g., Perez-Marcos, Sanchez-Vives, & Slater, 2012; Slater, Perez-Marcos, Ehrsson, & Sanchez-Vives, 2009) are now allowing for a great deal of progress to be made in terms of our understanding of this particular topic (e.g., Haggard, Taylor-Clarke, & Kennett, 2003; Moseley et al., 2012a; see Chapter 8).

Recent research on the representation of the human body has highlighted the degree of plasticity of this neural system (for example, by investigating whether or not artificial/prosthetic limbs or even tools can be integrated into the body representations; see Holmes & Spence, 2005; Spence, 2011c, for reviews; see also Carlson, Alvarez, Wu, & Verstraten, 2010), the constraints that affect processing of stimuli presented across, or close to, the body (e.g., Gallace, Tan, & Spence, 2006a, 2006b, 2007b), and the role of multisensory inputs in contributing to both the maintenance and updating of these representations (e.g., Makin, Holmes, & Ehrsson, 2008). Researchers have now

Table 1.1 Table summarizing the number of sensors, number of afferents, information transmission rates/channel capacity (from Zimmerman, 1989), % of attentional capture (from Heilig, 1992), and % of neocortex (Felleman & van Essen, 1991) relative to each sensory modality. See the main text for the limitations affecting the interpretation of these data.

Sensory system	Number of sensors	Number of afferents	Channel capacity (bits/s)	Psychophysical channel capacity (bits/s)	% attentional capture	% of the neocortex
Vision	2×10^8	2×10^6	10^7	40	70%	55%
Audition	3×10^4	2×10^4	10^5	30	20%	3.4%
Touch	10^7	10^6	10^6	5	4%	11.5%
Taste	3×10^7	10^3	10^3	1(?)	1%	0.5%
Smell	7×10^7	10^5	10^5	1(?)	5%	unknown

also begun to uncover the neurological substrates of body representation by means of the study of those patients affected by brain damage and by using brain-imaging technologies (e.g., Ehrsson, Holmes, & Passingham, 2005a; see Gallace & Spence, 2008a, for a review).

The theoretical reasons summarized so far are not the only ones supporting the possibility that the acceleration in tactile research that has been seen over the last few years won't end in disappointment; more practical and applied factors seem to play an equally important role. As already seen earlier in this chapter, the use of tactile innovations has never been so widespread in our everyday life. As far as this point is concerned, it's easy to think about the vibration ring mode of the mobile phone you may well have right now in your pocket (see Chapter 9), but other uses of tactile stimulation are less apparent though still important. Our houses are now filled with objects that have been specially designed to stimulate our skin (see Spence, 2002b). For example, one may consider the fact that the materials that are used to cover items that we constantly use (such as couches, carpets, bed sheets, toothbrush handles, and even deodorant sticks) are now sometimes specifically developed in order to provide particular patterns of tactile stimulation and therefore to elicit a given percept and even a given emotional experience in the end user (Spence & Gallace, 2011; Spence & Piqueras-Fiszman, 2012). Even for products in the technology sector, such as, for example, tablet PCs, mobile phones, and MP3 players, the importance of enhancing the tactile "feel" of the product is gaining in popularity among designers (see "Does it make sense?" 2007).

Designed pieces of furniture, such as tables or chairs, can be described as smooth, sensual, or, more generally, as having an important "tactile" component or feeling, one that discerning customers will pay a lot of money for. In addition to this aspect, one should also note that new forms of tactile art and design are quickly becoming an important part of our everyday hedonic experiences (e.g., Meyer, 2001; Street & Lewis, 2001), even where we do not necessarily expect to find them (such as in the packaging of many of the household products that we tend to buy on a regular basis; see Piqueras-Fiszman & Spence, 2012a; Spence & Gallace, 2011; see Chapter 11). In fact, recent advances in technology are increasingly enabling companies to create, at a relatively low cost, all manner of feels/shapes for everyday products and, equally important, for the packaging they come in.

It is no longer surprising to find products on the supermarket shelves that allow the user to touch what is inside, or to provide a part of the content on the container for the buyer to try and touch it! In fact, it has been estimated that customers who touch the clothing in the store are more than four times more likely to end up buying it (e.g., Spence & Gallace, 2011; see also Chapter 11). The importance of providing the customer with the possibility of touching the object on display somehow contrasts with other aspects of our tactile interactions with objects and requires innovative solutions. For example, the marketers need to deal with the fact that many people dislike (and do not wish to purchase) those products that have already been touched by someone else (such as the top newspaper on the pile; Argo, Dahl, & Morales, 2006).⁷ Similarly, if the reader ever visited Verona in Italy, he/she will probably be familiar with the statue of Juliet, the character depicted by William Shakespeare in his famous play *Romeo and Juliet*, placed in front of her historic house. The right breast of the bronze statue is very much shinier than the left, due to the fact that tourists often touch this part of the statue's body in order to promote fortune and good luck (note that many other similar examples can be found all over the world). In this case, our desire to touch

⁷ Note that this is certainly not the case for relics, where people actually want to touch things that belonged to a saint or holy person.

famous or even ancient objects (or relics) contrasts with the necessity of preventing the deterioration of precious artifacts, a problem that extends to museums and art galleries, requiring new and innovative solutions (see Chapter 12).

The way in which we get from A to B, not to mention our safety while out there on the roads, is also starting to be affected by touch technologies. For example, numerous different models of car are now equipped with vibrating devices designed to inform the driver about potential dangers, such as the “Lane departure warning system” developed by Citroën in 2004, that informs the car driver of any unintended line crossing by vibrating one side of the driver’s seat or the Advanced Vehicle Safety Management installed in the 2012 flagship models of the Kia car inform the driver by means of seat vibrations about possible collisions. The presence of these devices on our vehicles is likely going to increase, at least if the prediction made by Denso Corporation that the majority of commercial vehicles will be fitted with some kind of vibrotactile stimulation device by 2020 is to be realized (see Ho & Spence, 2008; Spence, 2012a; see also Chapter 10).

A number of recent advances in tactile technology would only seem to be related to certain specific domains (such as the military) with apparently little affinity with our everyday lives. For example, a number of devices have been developed to provide additional tactile stimulation to soldiers or fighter pilots (e.g., Baldwin et al., 2012; Sklar & Sarter, 1999). However, it is worth noting here that many of our everyday technologies, such as Teflon, Velcro, digital cameras, and microwave ovens,⁸ actually originated from previous military or space research. That is, a haptic interface guided by a global positioning navigation system for soldiers might one day successfully be used to provide directions to blind or sighted individuals while walking on a busy and noisy street.

Finally, it isn’t difficult to observe that touch is also widely adopted as an input to control many of the technological devices that we are now accustomed to using. Think, for example, of the “touch sensitive” buttons on our TV screens, laptops, and even on a number of common household electronic devices, such as coffee machines, microwaves, and blenders. Other uses of tactile technologies are now being developed at a rapid pace. This is the case of VR applications, where tactile sensations might provide an important contribution to the feeling of presence (see Chapter 9), but also of telemanipulation, human–machine communication interfaces, and robotics.

All of the aspects summarized in this chapter would therefore appear to suggest that it is unlikely that the recent expansion in the study and use of touch in our society will suddenly stop. It is difficult to determine whether we will move from a “visual” to a “tactile” or even to a “multisensory” society in the future. However, what we can say with some degree of certainty is that other sensory modalities are going to assume a greater importance in our lives in the years to come. It should, however, be considered that in order to turn this possibility into a reality, there is still a great deal of empirical work to be done. In particular, virtually no attempts have yet been made to unify the field of research on touch into a proper science with a clear perspective oriented toward the application of the understanding to the constraints and opportunities of the real world. One of the aims of this book, then, is to try to move toward this goal. In particular, in this book, we have attempted to integrate a number of the most important recent advances in the study of touch that have emerged from different research fields (from anthropology to ergonomics, and from neurophysiology to cognitive science), in order to provide a more holistic viewpoint on the topic (a robust multidisciplinary base upon which the future knowledge of touch can be built).

⁸ A development from experimentation on aircraft tracking radars.

The connection behind all of the different aspects of tactile research will be the insights provided by the cognitive neurosciences and the relevance of this research for future applications in many different aspects of our everyday interactions.

This volume is addressed to a wide readership, one that includes researchers and engineers who would like to use tactile stimulation in applied settings, but also to cognitive scientists, artists, designers, and a lay readership, in other words anyone who is interested in knowing more about the(ir) sense of touch, its limitations, and its future potential. This book will direct the reader through a number of different intriguing and important questions such as the following: Can tactile sensations be attributed to different positions from where our body actually is? What exactly is the difference between a sensual stroke and the feeling of another person accidentally nudging our arm? Can we use touch to communicate emotions? Under what conditions is touch more accurate than the other modalities (such as vision and hearing)? What are the limitations affecting the sense of touch? Why do people like to cuddle? Why is the feel of the “cozy” blanket such an important transition object for young children (e.g., Busch, Nagera, McKnight, & Pezzarossi, 1973)? Why do collectors get such pleasure from feeling/touching the objects in their collection? Can one make “better” art by more effectively exploiting tactile sensations? Will “artificial touch” be a practical possibility in the near future? How can we remember the softness of our first teddy bear? How can we shape our environment according to our “tactile” needs (and capabilities)? Why, and under what conditions, do we sometimes fail to detect even important changes in tactile stimulation (such as when our wallet slips out of our pocket, or, more likely, is removed by a pick-pocket)? Why do people sometimes feel the urge to touch soft and/or tender objects (such as a baby’s cheek)? Why are we more likely to buy something if we can feel it first in our hands, or between our fingertips? How can designers/marketers make products and/or packaging that are more appealing to the customer’s touch? How do we integrate tactile sensation with the visual, auditory, olfactory, and gustatory aspects of our environment? In the pages that follow, we will accompany the reader through many different aspects of what may be defined as the “world of touch,” answering some of his/her questions and opening the door to many others.

1.3 Overview of the book

In this volume, we have attempted to summarize the latest knowledge that has been developed from the emerging body of cognitive neuroscience research on tactile information processing in humans. Our ultimate aim is to clarify how the insights arising from the study of touch in the laboratory can be used to help enhance modern technologies, such as those involved in the development of VR environments or those related to applied contexts such as marketing, videogaming, telesurgery, the development of enhanced sensory substitution systems, art experiences and the creation of replicas, and man–machine interface design. In order to do this, the book is divided into four main sections. The first two sections (A, B) are devoted to providing a complete overview of the state-of-the-art of scientific research on tactile perception. In this part of the book, the emphasis is primarily on the more fundamental aspects of tactile information processing (i.e., those relating to consciousness, memory, attention, and to the social, sexual, and representational aspects of touch) while the more peripheral aspects of tactile sensations (i.e., the physiology of touch and the basic principles of tactile perception) are discussed more briefly.⁹ In the third and

⁹ Even if the reader who is interested in the more applied aspects of touch might simply skip this part of the book (e.g., Chapter 2), our experience with the applied domain suggests that the more applied aspects of touch cannot easily be detached from the study of their physiological bases.

fourth sections of the book (C, D), we concentrate on extending the knowledge gathered by cognitive neuroscientists regarding the sense of touch to the applied field. That is, the potential application of scientific knowledge on tactile information processing to the domains of VR, to the development of warning signals for vehicles, to the design of more engaging videogames, to the development of sensory substitution systems for individuals with some form of sensory impairment, to marketing and product design, art appreciation, and even to two of life's most pleasurable activities, sex and gastronomy, will be discussed. Finally, the book concludes with an analysis of how scientific research (both theoretical and applied) on touch will need to proceed in the future and how the results of such research may change the way in which we live in the years to come.

The fundamentals of touch: The organization of the somatosensory system

2.1 Introduction

Our skin offers us effective protection against many mechanical, thermal, chemical, and microbial dangers. At the same time, receptors within this, the largest of our bodies' sensory organs, and the neural system that they connect with, provides us with the most fundamental and direct means of contact with the outside world (e.g., Barnett, 1972; Gottlieb, 1971; Gregory, 1966). This complex system might be considered the most powerful interface ever designed between our self and the objects that surround us. One should, however, consider the fact that what we commonly define as "touch" is actually the product of multiple forms of sensory integration occurring at different stages of neural information processing. That is, our experience of touch results from the synergistic activity of multiple distinct neural systems (that certain researchers treat as separate systems, or modalities of touch, and which others consider as submodalities of touch) responding to touch, pressure, temperature, pain, itch, joint position, muscle sense, and movement (see Berkeley & Hubscher, 1995; Iggo, 1977; McGlone & Reilly, 2010). Moreover, tactile sensations can arise from the microgeometric, macrogeometric, and spatial properties of the stimuli concerned (see Lederman, 1974; Roland & Mortensen, 1987). The microgeometric aspects of a surface concern, for example, the texture, roughness, stickiness, and spatial density of the surface (see Bensmaia & Hollins, 2005). The macrogeometric stimulus properties, meanwhile, consist of the shape, size, and structure of objects, while the spatial properties regard the location of the tactile stimuli (coded on the basis of a given spatial coordinate system (what is known as a "frame of reference") centered on the body midline, on a given part of the body, on external space, or even on an object/tool; see Spence, 2011c; Spence & Driver, 2004, for reviews). All of these different aspects of the stimuli that come into contact with the surface of our body are coded by means of different combinations of receptors in the skin and can clearly be differentiated from a phenomenological point of view. Many tactile sensations such as wetness, pressure, vibration, tickle, and tingling are considered by researchers to be "sensory blends," resulting from the activation of multiple receptor systems (e.g., Bentley, 1900; Selden, 2004).¹ That is, there is no single class of receptors

¹ The reader might try the following example, first reported by Bentley in 1900. Put on a pair of surgical gloves and insert one hand into a bowl of cold water, and the other hand into a container of warm water. The hand placed in the cold water should feel wet, while the hand in the warm water should feel dry. This demonstrates that the perception of wetness is mediated by a combination of pressure and temperature signals from different skin receptors. Note that in neither case is your hand actually wet.

in the skin that, when activated, codes for the perception of wetness, oiliness, or greasiness, say. Similarly, the perception of certain qualities of a stimulus analyzed by a particular class of receptors can be affected by other qualities of the stimulus, analyzed via a different class of receptors. For example, the colder of two identical objects will normally be felt as heavier (e.g., Sherrick & Cholewiak, 1986).²

It is important to note here that the fact that our sense of touch is mediated by receptors located in the skin, does not necessarily mean that the “perceptual field” of this sensory system is limited to the body surface. In fact, “distal attribution” (that is, the ability to locate a stimulus as occurring away from the receptor surface)³ also applies to the sense of touch (e.g., Bach-y-Rita, Collins, Saunders, White, & Scadden, 1969; see also Chapter 9). Similarly, tactile stimuli can sometimes be perceived on bodily locations where no tactile receptors are actually present, or even outside of the body surface itself (e.g., Miyazaki, Hirashima, & Nozaki, 2010; see also Chapter 8). Note here that the functioning of the mechanisms related to the perception and localization of tactile sensations sometimes give rise to interesting illusions. So, for example, in the so-called “Aristotle illusion” (McKeon, 1941), if you cross two adjacent fingers (of one hand) one over the other and rub your fingers up and down along the bridge of your nose (or along the edge of a table) you may well experience the sensation of touching two noses (or table edges).⁴

Finally, one should consider the fact that the feeling of an object held in our hands (such as in the case of a manipulated object) is rather different from the feeling of a caress on our arm delivered by a loved one. One might therefore wonder whether or not these two rather dissimilar stimuli are somehow treated differently by the brain as well. In fact, as we will see later in this chapter, different nerve fibers and different regions of the brain constitute part of a network dedicated to the more social and “pleasant” aspects of tactile perception (e.g., Francis et al., 1999).⁵ That is, emotional/hedonic touch can be differentiated from perceptual touch at many different levels of neural processing.

In this chapter, we summarize the characteristics of the systems responsible for translating information occurring on/to the skin into neural signals and for conducting these signals to central processing networks within the brain. In particular, after having described the main classes of receptors found in the skin, we will analyze the different pathways that tactile information utilizes in order to reach the brain. Finally, the main neural networks within the neocortex involved in the processing of different aspects of tactile information will be defined.

² For example, try to take two identical metal coins and place one in the freezer until it is very cold. Then place both of them on your forehead. The cold coin should feel heavier than the warm coin (see also Hayward, 2008, for a review of tactile illusions that can be tried at home).

³ It is important to note here that also visual stimuli, even if generated by the transduction of a physical signal into a neural signal occurring on the retina, are not perceived as arising from the position where this process occurs but are projected into external space.

⁴ Interestingly, Benedetti (1985, 1988a, 1991) reported a series of studies in which he had participants cross their fingers for 6 months, or until they dropped out of the study. He demonstrated that the Aristotle illusion could also be induced with uncrossed fingers (if one's fingers normally happened to be crossed). This result clearly highlights the malleability of our neural representations of the body.

⁵ Here it is worth noting that somatosensory experiences might be divided into extrapersonal, such as when we explore a surface with our hands, intrapersonal, as when we feel the surface of our body or its position, and interpersonal, when we touch another person (Bolanowski et al., 1999).

2.2 Tactile receptors

Different tactile receptors innervate different parts of the skin, glabrous and hairy (see Figure 2.1 and Table 2.1; see also Iggo & Andres, 1982; Kandel, Schwartz, & Jessell, 2000; Light & Perl, 1984). Glabrous skin is thicker and less permeable than hairy skin, and is only found on the palms of the hands, the soles of the feet, and parts of the genitals (note that the lips are considered more of a transitional region between glabrous and hairy skin). Non-glabrous skin covers the rest of the body surface, even if different regions of the skin differ markedly in terms of hair density. Stimuli occurring on both the glabrous and hairy skin are translated into neural signals by means of mechanoreceptors. The mechanoreceptors are characterized by specialized end organs that surround the neural terminals and transduce information from the external world into electrical signals (e.g., Darian-Smith, 1984; Lumpkin & Caterina, 2007; see Lumpkin, Marshall, & Nelson, 2010, for the role of “force sensing” in the development and survival of multicellular organisms). The general principle of functioning of a mechanoreceptor is that a mechanical stimulus delivered to the body elicits a deformation of the skin surface that, in turn, causes a deformation of the end organ of a sensory neuron (see Lumpkin, et al., 2010). By changing the excitability of the neuron’s membrane, a “generator potential” is created, that is directly related to the amount of deformation (e.g., the greater the deformation, the greater the potential). Whenever the potential reaches a certain threshold (known, unsurprisingly as the firing threshold), it triggers a volley of “action potentials.” The stimulus then becomes codified into the frequency of the action potentials within the neuron. For example, the more intense, or rapid, the deformation in the end organ, the higher the frequency of action potentials generated in the sensory neuron (see Chalfie, 2009, for the cellular mechanisms underlying this form of neural transduction).

Different end organs are specialized for transducing different forms of mechanical stimulus energies and have peculiar patterns of response (e.g., Schmelz, 2011). The Pacinian corpuscles are most commonly found on the palms of the hands and soles of the feet, as well as, even if less commonly, in erogenous zones such as the nipples and genitals (see Chapter 13). The Pacinian corpuscles respond to the deformation of the skin, such that the greater the deformation, the

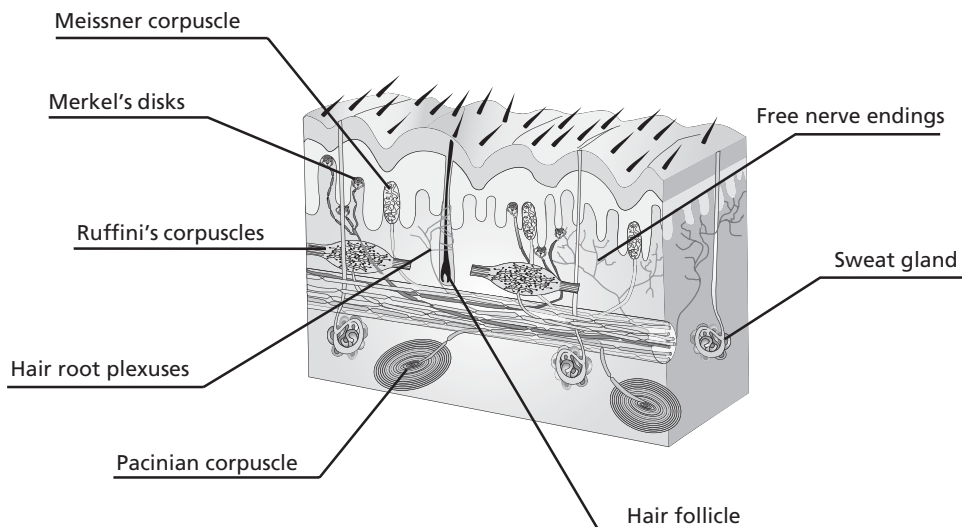


Fig. 2.1 Section of the skin highlighting different tactile receptors.

Table 2.1 Tactile receptors, their main characteristics and the sensations that they contribute to eliciting.

Receptor type	Body area	Innervating fiber	Pattern of response	Activating stimulus	Receptive field size	Ascending pathway	Sensation
Pacinian corpuscles	Hairy and glabrous skin	A α , β	Rapidly adapting type I	Vibrations 200–300 Hz	Large	DCML	High frequency vibrations
Ruffini's end organs	Hairy and glabrous skin	A α , β	Slowly adapting	Skin deformation	Large	DCML	Tension deep in the skin
Meissner's corpuscles	Glabrous skin	A α , β	Rapidly adapting type II	Vibrations around 50 Hz	Small	DCML	Changes in texture
Merkel's disks	Glabrous skin	A α , β	Slowly adapting	Pressure	Small	DCML	Sustained touch and pressure
Free nerve endings	Hairy and glabrous skin	A δ , C	Slowly adapting	Tissue damage; Contact; Temperature change	Large	Anterolateral system	Contact, pressure and stretching
Hair follicle receptors	Hairy skin	A β	Rapidly adapting type I	Position changes of hairs	Small	Anterolateral system	Stroking

DCML = dorsal column-medial lemniscus (see section 2.3 for a description of this and of the anterolateral ascending systems)

greater the generated potential. The Meissner corpuscles are concentrated in the glabrous skin situated in the extremities, especially in the fingertips, and are thought to be partially responsible for the high tactile sensitivity that is normally observed in these body sites. In fact, different areas of the body have different tactile sensitivities with the fingertips and lips having the lowest sensory thresholds (meaning that a weaker stimulus can be detected) for the detection of an individual stimulus or pairs of stimuli (e.g., Weinstein, 1968).⁶ More generally, the sensitivity of a particular region of the skin depends on the number of receptors that innervate it. The fingertips and tongue have as many as 100 receptors per square cm, while the back of the hand has fewer than 10. On the fingertips, this number drops between the ages of 12 and 50 years and most probably beyond (note that no participants over the age of 50 were tested in the study), leading to an age-related loss in tactile sensitivity to relatively small stimuli (e.g., Thornbury & Mistretta, 1981; but see Stuart, Turman, Shaw, Walsh, & Nguyen, 2003, for an age-related increase in sensitivity threshold for vibrations presented on the forearm, shoulder, and cheek).⁷ The Meissner

⁶ Two-point discrimination acuity is less than 1 mm for the fingertips, about 15 mm for the forehead, 35 mm for the forearm, 39 mm for the back, and 45 mm for the calf.

⁷ Not only does tactile sensitivity decline with age, more central neural mechanisms such as those related to the deployment of attention are also thought to suffer from an age-related decline as well (e.g., Hugenschmidt, Peiffer, McCoy, Hayasaka, & Laurienti, 2009; Laurienti & Hugenschmidt, 2012).

corpuscles are located superficially in the dermis and contribute to the perception of the shapes of the objects held in the hands.

In addition to mechanoreceptors with specialized end organs, tactile sensations can also be transduced by means of unspecialized free ending terminals. In this case, the neural fibers conducting the signal to the brain terminate directly in the skin, muscle, or joints. These endings are unmyelinated, that is, they are not encapsulated (see Purves, Augustine, Fitzpatrick, Katz, LaMantia, McNamara, & Williams, 2004). They are not associated with any particular kind of tissue but their sensitivity to specific stimuli (e.g., to touch rather than to proprioception or muscle contraction or relaxation) is determined by the location of the receptor and by the tissue surrounding the terminal (e.g., muscle vs. dermis). These endings can be stimulated by touch, pressure, thermal, chemical, or painful stimuli. The sensation of “itch” results from the stimulation of these free nerve endings by certain chemicals, such as bradykinin, often as a result of a local inflammatory response (see Schmelz, 2010).

Certain endings wrap around hair follicles in hairy parts of the skin and result in particular kinds of tactile receptors, the hair root plexuses (e.g., Kandel, Schwartz, & Jessell, 2000; Purves et al., 2004). These receptors can detect movements on the skin surface that disturb the hairs. That is, they are responsible for feeling light tactile stimuli, such as a small insect crawling on our skin or a lover blowing gently on one’s ear.

While free receptors are found in the hairy regions of the skin, hairs per se are not essential for the appreciation of touch or pressure. In fact, the removal of hair follicles has been shown to result in only a relatively small rise in the tactile pressure threshold in the non-glabrous skin (e.g., Tobin, 2011). By contrast, the removal of hairs has an important impact on the ability of people to perceive surfaces as wet (see Ackerley, Olausson, Wessberg, & McGlone, 2012; cf. Sato, Miyake, Hashimoto, & Kajimoto, 2010).

The mechanoreceptors can be differentiated as a function of their frequency of firing to mechanical stimulation: they are distinguished as either slowly or rapidly adapting (e.g., Vallbo, Olausson, Wessberg, & Kakuda, 1995; see Figure 2.2). Slowly adapting receptors, such as Merkel cell–axon complexes and Ruffini corpuscles, also continue to respond for a certain amount of time under conditions of constant stimulation (see Birznieks, Macefield, Westling, & Johansson,

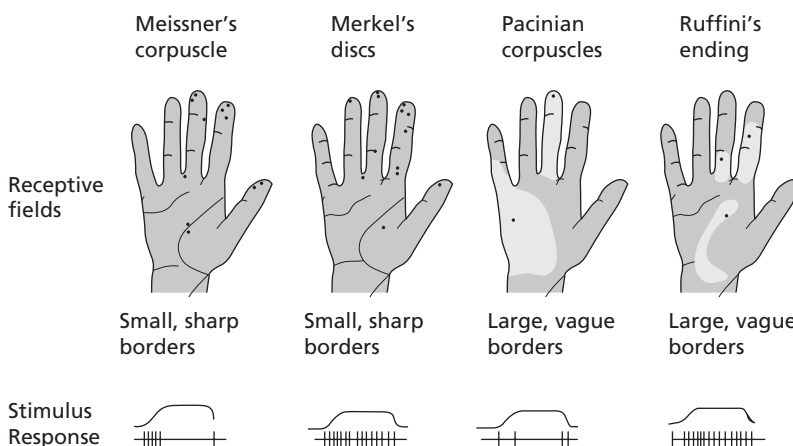


Fig. 2.2 Patterns of activation and size of receptive field (represented by black dots and gray areas) of different types of cutaneous mechanoreceptors.

2009). That is, their responses are maintained for the duration of the presentation of the eliciting stimulus. They give rise to the perception of form and roughness by the skin (e.g., Knibestöl, 1975). By contrast, rapidly adapting mechanoreceptors, such as Meissner and Pacinian corpuscles (see Gescheider & Wright, 2012), and the root hair plexuses, only respond to the onset and offset of stimulation (a deformation of the skin) and they cease to discharge after a few seconds, even if the stimulus remains on the skin. They contribute to the perception of flutter and slip. In addition to the mechanoreceptors, other classes of receptors mediate sensations regarding our body and its surface. In particular, thermoreceptors code absolute and relative changes in temperature, within a non-painful range of temperatures (e.g., Darian-Smith, Johnson, LaMotte, Shigenaga, Kenins, & Champness, 1979; Patapoutian, Peier, Story, & Viswanath, 2003; Schepers & Ringkamp, 2010). Not all of these receptors, though, have end organs at their extremities. Different classes of thermoreceptors are specialized for certain quantities of stimulus energy, such that some receptors respond to lower temperature ranges while others respond to higher ranges of temperature. Interestingly, these kinds of receptors, just as for the case of other receptors seen earlier in this chapter, are not distributed homogeneously across the body surface. For example, if you take a stimulus at room temperature, such as a biro, and drop it on different points on the back of your hand, you will feel the cold tip of the pen at certain points on the skin surface but not at others, as a function of whether the tip of the pen lands on a cold receptor or not.

Nociceptors respond to potentially damaging stimuli impinging on the skin or internal organs and can be classified as thermal, mechanical, and chemical as a function of the type of stimulus that activates them (e.g., Burgess & Perl, 1973; Dubin & Patapoutian, 2010). Some of these receptors are polymodal while others are silent.⁸ Polymodal receptors not only respond to noxious stimuli (i.e., chemicals), but are also activated by intense mechanical stimuli and heat (see Baumgärtner, Greffrath, & Treede, 2012; Zimmerman, 1986). This class of receptors also has free nerve endings. Finally, proprioceptors provide information regarding the position, direction, and velocity of movement in the joints. They can be found in muscles, tendons, joints, and even in the inner ear (e.g., Macefield, 2005; Macefield, Gandevia, & Burke, 1989; McCloskey, 1978; Proske & Gandevia, 2009; see also Cordo, Horn, Künster, Cherry, Bratt, & Gurfinkel, 2011). Even if not solely related to our conscious experience of touch, proprioception plays a major role in our haptic perception. In fact, the perception of certain qualities of 3D stimuli, such as their shape, curvature, weight, and solidity, requires the computation of information from the joints and muscles in order to be experienced properly (e.g., Carello & Turvey, 2000; Giachritsis, Wright, & Wing, 2010; Heller, 1992, 2004; Johnson & Hsiao, 1992; Konczak, Li, Tuite, & Poizner, 2008).

Here it is important to highlight the fact that certain tactile sensations require the integration of information from more than one class of receptors (e.g., mechanoreceptors and thermoreceptors). For example, the perception of “wetness” on the skin requires the activity of low-threshold mechanoreceptors, as well as that of thermoreceptors that are sensitive to cold. This sensation depends on the integration of different inputs arising from the same region of the skin. For this very reason, tissues that aren’t innervated by both classes of receptor cannot support the sensation of wetness (e.g., a mouthful of beer will be perceived as cold but critically not wet when swallowed, because the esophagus is not innervated by low-threshold mechanoreceptors; e.g., Rogers, Hermann, & Travaglini, 1999; see also Mason, 2011). Similarly, wet stimuli that activate only one

⁸ Silent or “sleep” nociceptors are normally unresponsive to noxious mechanical stimulation, but become responsive to mechanical stimulation during inflammation and after tissue injury (e.g., Schmidt, 1991; Schmidt, Schmelz, Torebjörk, & Handwerker, 2000).

class of receptors, but not the other, will not be perceived as wet. That is, water at skin temperature will not be sensed as wet (because of the lack of activity in the cold thermoreceptors), nor is a still hand submerged in cold water (because of the lack of activity in the low-threshold mechanoreceptors). The oily sensation that you experience when holding a fresh fish in your hands provides another example of the sensory blending of the information provided by different classes of receptors (e.g., see Bentley, 1900).

The perception of wetness is not an isolated case of the multisensory interaction⁹ between sensory signals (what we might call a “synthetic tactile experience”). The sensation of tickle is also thought to be attributable to the activation of different classes of receptors, the free nerve endings and the Pacinian corpuscles (e.g., Ackerley et al., 2012; Selden, 2004). Note, however, that this particular sensation typically arises only when someone else touches you, but not when you touch yourself. This is due to the interaction between the sensory and motor systems in the perception of touch. In particular, it has been suggested that a forward model able to predict the sensory consequences of movement based on the motor command might be responsible for this puzzling phenomenon (Blakemore, Wolpert, & Frith, 2000). That is, on the basis of this model, when a movement is self-produced, its sensory consequences can be accurately predicted. These predictions can then be used to attenuate the sensory effects of the movement resulting in an absence of tickling sensations. That is, interactions occur at many different levels of information processing and are responsible for the qualities of our sensations referred to stimuli that touch our body (see also Fabrizi, Slater, Worley, Meek, Boyd, Olhede, & Fitzgerald, 2011). The occurrence of these multiple interactions might also explain why it is that people tend to find that shaking a warm hand is somehow more pleasant than shaking a cold one (see also Rolls, Grabenhorst, & Parris, 2008; Williams & Bargh, 2008). It is also important to note that despite the large number of studies that have investigated the mechanisms of transduction of external stimuli into tactile sensations over the course of the last 20 years, the majority of them have been performed on lower animals (simple or primitive animals, such as *Caenorhabditis elegans* and *Drosophila*). This has led some researchers to suggest that the analysis of tactile reception in mammals is still “in its infancy” (Lumpkin et al., 2010).

2.3 Pathways for the conduction of tactile information to the central neural system

Once information from the skin and body is translated by means of receptors into neural signals, it needs to be transferred to higher processing centers within the central nervous system by means of specific neural fibers. These fibers differ mainly in terms of the speed with which they conduct neural signals, which, in turn, depends on the diameter of the fiber and on the presence/absence of a myelin sheath covering the fiber (e.g., Cummins, Dorfman, & Perkel, 1981; Hursh, 1939; Tackmann, Spalko, & Oginszus, 1976). In particular, the larger the diameter of the fiber, the faster the speed of neural conduction. Moreover, within the myelinated fibers, the action potential leaps from node (parts of the fiber that are not covered by myelin) to node along the axon, reaching a much higher speed than in unmyelinated fibers (e.g., Sherwood, 2004). It is possible to experience the consequences of the different times of arrival of tactile information for yourself. If you rub the tips of your two middle fingers against each other you should feel the sensation of touch

⁹ Note that here “multisensory” is used to describe a process that derives from the synthetic processing of information arising from multiple skin receptors and neural fibers.

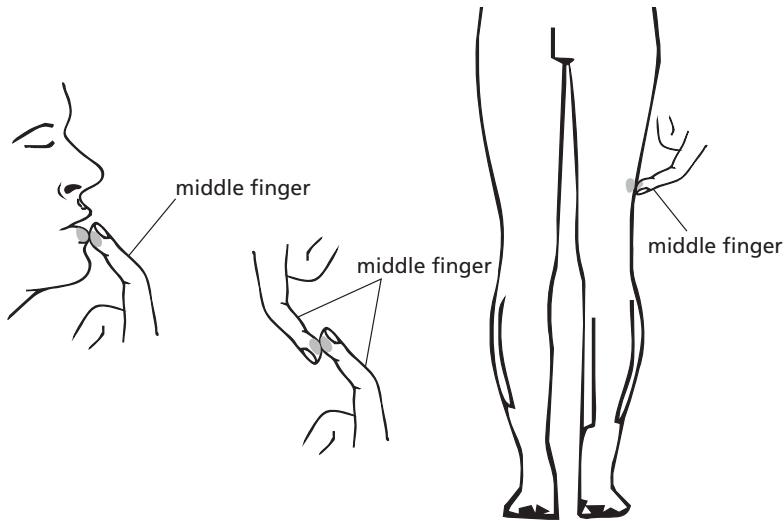


Fig. 2.3 Representation of the areas of the skin that if self-touched give rise to different localizations of tactile sensations; see section 2.3 for a description.

as being localized between the two fingertips as shown in Figure 2.3. However, if you now rub one finger against your lip, you should feel the sensation of touch residing almost exclusively on your lip instead (i.e., and not on your fingertips). Finally, try touching your thigh with your index finger, you should now feel the tactile sensations residing not on your leg, but almost exclusively on your finger (see von Békésy, 1963). von Békésy argued that this effect is due to slight differences in the amount of time that the various tactile signals takes to reach your brain from different body sites (situated at different distances from the brain; see also Bergenheim, Johansson, Granlund, & Pedersen, 1996; Halliday & Mingay, 1964; Klemm, 1925). Note, however, that differences in tactile sensitivities in different body locations might also contribute to eliciting the effect popularized by von Békésy (see Weinstein, 1968).

The different speeds of the nerve fibers that conduct signals from the skin to the central nervous system has been suggested to explain why it is that whenever we are injured, we can normally get some pain relief simply by rubbing the affected area of the body. That is, following on from the “gate theory” proposed in the early 1960s by Ronald Melzack and Patrick Wall (e.g., Melzack & Wall, 1962; though see Nathan & Rudge, 1974, for evidence contradicting the theory; see Melzack, 1996, for a more recent discussion of the limits of the theory), the spinal cord contains a theoretical “gate” (i.e., an inhibitory neural mechanism) that can allow or block the passage of signals generated by noxious stimuli to the central nervous system. At the level of the gate, different neural fibers converge, and the first signals that enter the gate control its opening (by inhibiting the other signals that reach the gate subsequently). Given that the noxious signal (at least for “second” or “burning” pain) is carried by C fibers (that have a lower conduction velocity than A β or A δ fibers, responsible for the conduction of non-noxious somatosensory signals as well as for pricking pain—“first pain”; see also later discussion), whenever we rub (or place a cold object over) the part of the body that hurts, the signals carried by the fastest non-noxious fiber reaches the gate first and thus inhibit the signals generated by the noxious stimulus (by closing its passage to the central nervous system). Consequently, we feel less pain (e.g., Dickenson, 2002; Macefield, Gandevia, &

Table 2.2 Speed of conduction of neural fibers.

Fiber	Diameter	Speed of conduction
A α	13–20 μ m	80–120 m/s
A β	6–12 μ m	35–75 m/s
A δ	1–5 μ m	5–30 m/s
C	0.2–1.5 μ m	0.5–2 m/s

1 μ m = 10^{-6} meters; m/s = meters per second.

Burke, 1989; Melzack & Wall, 1962; see von Békésy, 1963, for an early discussion on the different conduction rates of neural fibers; see also Bergenheim et al., 1996).

Interestingly, the differing speeds of conduction of different neural fibers also accounts for the subjective experience of first and second pain: The delivery of a single *painful* stimulus will evoke two successive and qualitatively distinct sensations referred to as *first* and *second pain* (e.g., Bishop & Landau, 1958; Price & Dubner, 1977; see also Ploner, Gross, Timmermann, & Schnitzler, 2002; Veldhuijzen, Nemenov, Keaser, Zhuo, Gullapalli, & Greenspan, 2009). First pain is brief, pricking, and well localized on the skin surface, and its perception results from the activation of myelinated A δ fibers. Second pain is longer-lasting, burning, and is associated with a burning sensation and tends to be less well localized. It results from the activation of unmyelinated C fibers that conduct the neural signal more slowly than A δ fibers (see Table 2.2). Thus, certain qualitative and temporal aspects of our perception would seem to be mediated by the speed of conduction of neural fibers.

2.3.1 CT fibers: A privileged pathway to pleasant tactile sensations

Mechanical and proprioceptive stimuli are conducted primarily by myelinated A α , and A β fibers while thermal and noxious stimuli are conducted by A δ , and unmyelinated C fibers. Note, however, that in various mammals, the transmission of mechanical information is dual and comprises not only myelinated afferents but also unmyelinated C afferents (e.g., Bessou, Burgess, Perl, & Taylor, 1971). The presence of C fibers conducting mechanoreceptive information in humans has, for a long time, been dismissed (e.g., Kumazawa & Perl, 1977, for the suggestion that that C low-threshold mechanoreceptors are only vestigial; see also Vallbo & Johansson, 1978), until relatively more recent times when their presence in the hairy skin of the forearm was finally demonstrated (e.g., Cole, Bushnell, McGlone, Elam, Lamarre, Vallbo, & Olausson, 2006; Liu, Vrontou, Rice, Zylka, Dong, & Anderson, 2007; Nagi et al., 2011; Vallbo, Olausson, & Wessberg, 1999; Wessberg, Olausson, Fernstrom, & Vallbo, 2003). These fibers, that nowadays are defined as CT (C tactile) afferents, in order to differentiate them from other C fibers, respond particularly vigorously to the slow stroking of the skin (within a velocity range of 1–10 cm/s; see Loken et al., 2009), but relatively poorly to rapid deformations of the skin surface (e.g., Bessou, Burgess, Perl, & Taylor, 1971; Iggo, 1960; see also Olausson et al., 2008). Note that the range of velocities that give rise to the most vigorous activity in the CT fibers are also the same as that inducing the highest subjective perception of pleasant touch (Essick et al., 2010; Loken et al., 2009).

Currently, it remains somewhat controversial as to whether or not the impulses carried by CT fibers have access to consciousness. Note, however that the suggestion has been made that the activation of CT afferents might add particular qualities (or tint) to sensations elicited by the activation of other fibers rather than directly eliciting specific percepts (see Vallbo et al., 1999; see also Nagi, Rubin, Chelvanayagam, Macefield, & Mahns, 2011, for the observation that the

stimulation of CT fibers during underlying muscle pain can evoke an overall increase in the perceived intensity of pain).

Given the response properties and slow conduction velocity of CT afferents, it has been suggested that they are not that important when it comes to the more cognitive aspects of tactile perception (e.g., Olausson et al. 2002). One might then wonder about the function of these conductive fibers. As far as this question is concerned, Loken et al. (2009) have suggested that they might constitute a “privileged peripheral pathway for pleasant tactile stimulation that is likely to signal affiliative social body contact” (p. 547). That is, the unmyelinated mechanoreceptors likely form part of a circuit that is responsible for coding pleasant tactile sensations, such as caress-like touch (e.g., stroking) between individuals and they may perhaps also be involved in sexual behavior (e.g., Morrison, Loken, & Olausson, 2010; see also Chapter 13). In support of such a hypothesis, the signals conducted by the CT fibers follow neural pathways that are distinct from those of myelinated tactile fibers. In fact, while C-tactile stimulation activates the dorsal posterior insula, an area of the brain that has been implicated in the processing of somatic affect, information conducted by A-beta afferents, is processed in the somatosensory cortex (where a more analytical sensory processing of the stimuli takes place; see McGlone, Olausson, Boyle, Jones-Gotman, Dancer, Guest, & Essick, 2012, on this point).

On the basis of the observations summarized in this section, one might wonder whether tactile sensations, just as previously demonstrated for the perception of pain, can be differentiated in first and second touch, where the former (discriminative touch) relies on fast conducting myelinated afferents, and the latter (affective touch; see Vallbo, Olausson, & Wessberg, 2007) on slowly conducting C fiber (McGlone, Olausson, Boyle, Jones-Gotman, Dancer, Guest, & Essick, 2012).

2.3.2 Ascending neural pathways

There are three specific ascending neural pathways to the central neural system, namely the dorsal column-medial lemniscus, the anterolateral system, and the somatosensory pathways to the cerebellum. The anterolateral system transmits information concerning nociceptive, thermal, and crude touch to higher brain centers. Note that crude touch¹⁰ allows an individual to perceive that something has touched them, without their necessarily being able to localize precisely where they were touched.¹¹ In this system, the first-order neuron (the first in the chain that conducts the signal to the cortex) is found in the dorsal root ganglion, and communicates through synaptic connections to the second-order neurons in the dorsal horn of the spinal cord. Here, a decussation occurs, that is, a crossing from one side of the neural system to the other (e.g., Casey, Jones, & Willis, 2010), such that stimuli arising from the left side of the body are transmitted to the right side of the nervous system. The third-order neurons are located in the thalamus and transmit information to the cerebral cortex.

The dorsal column-medial lemniscal pathway relays discriminative tactile, vibratory, and proprioceptive sensations and is composed of rapidly conducting myelinated fibers. Within this system, the axon of the first-order neuron enters the dorsal column of the spinal cord and then ascends toward the secondary neuron located at the level of the medulla. Here the axons of the secondary neurons decussate and travel up the brainstem as the medial lemniscus (that gives the

¹⁰ Note that the poor localization of crude touch sensations is related to the large receptive fields of the stimulated receptors connected to these fibers and that we are, in general, always capable of correctly localizing a tactile stimulus because fine touch signals are concurrently processed by the brain.

¹¹ As yet, though, no study has identified the neural pathway of CT fibers.

name to the system) on the contralateral side. The axons ascend toward the thalamus where they synapse with the third-order neuron that project to the somatosensory cortex.

The somatosensory pathways to the cerebellum relay primarily proprioceptive rather than purely tactile information (e.g., Patestas & Gartner, 2006). However, in contrast to the proprioceptive information carried by the dorsal column-medial lemniscal pathway, the information carried by the somatosensory pathways to the cerebellum does not enter into consciousness. Rather, information in this system is transmitted directly to the cerebellum without projecting to the thalamus or to the cerebral cortex. Unlike the sensory pathways described earlier, where decussations¹² occur at different stages of neural transmission, signals arising from the left side of the body project to the left side of the cerebellum.

Lesions to each of these conductive systems selectively impair an individual's ability to process information from their body, a condition known as "deafferentation" (e.g., Rothwell, Traub, Day, Obeso, Thomas, & Marsden, 1982). Patients suffering from this condition may well experience difficulties in fine tactile manipulations as well as in performing even simple movements without constant visual control (due to a lack of proprioceptive information; e.g., Hocherman, 1993; Rothwell et al., 1982). Moreover, following amputation, deafferentated patients often present with phantom limb pain (e.g., Giummarra & Moseley, 2011; Kern, Busch, Müller, Kohl, & Birklein, 2012; Melzack, 1989, 1992; Subedi & Grossberg, 2011). That is, they report the presence of intense and complex pain sensations arising from the amputated region of their body (the phantom; see also Chapter 8). Recent theories suggest that this phenomenon might result from the lack of proprioceptive information regarding the missing limb (e.g., Moseley, Gallace, & Spence, 2012a). That is, information carried by each neural fiber would seem to be relevant not only for perceiving certain qualities of stimuli presented on the body, or the current position of our body, but also to maintaining a coherent representations of our body and to prevent potentially relevant dysfunctions to these representations.

2.4 Touch in the central neural system

2.4.1 The organization of the somatosensory cortex

Stimuli presented to just one side of the body (and described as unilateral sensory stimuli) from the sensory receptors distributed across the body surface, are transmitted either by the primary afferent fibers of dorsal root ganglia, or by the trigeminal sensory neurons, to the ventral posterior lateral and medial nuclei of the thalamus. From there, the majority of them then project to the contralateral primary somatosensory cortex (e.g., Blatow et al., 2007; Gardner & Kandel, 2000; Jones, 1986). The primary somatosensory cortex (SI) comprises Brodmann's areas 3a, 3b, 1, and 2 (in this rostral-caudal order), and it is located in the postcentral gyrus of the brain. SI is involved in the central processing of both tactile and nociceptive stimuli (e.g., Kaas 1990; Kenshalo & Willis, 1991).

Animal studies have revealed that neurons within each cortical site in SI (particularly those in layer IV) are arranged in columns that represent specific regions of the body (note that a similar columnar organization also characterizes the neural map present in human area VI; e.g., Hubel & Wiesel, 1962; Mountcastle, 1957; see Swindale, 2001, for a discussion of the concept of *cortical maps* for the different senses). This observation has also been confirmed in humans by direct stimulation of the brain in those patients who are awake just prior to undergoing surgery. Specifically,

¹² A crossing of neuron axons in the nervous system.

it turns out that the organization of SI is somatotopic (e.g., Penfield & Boldrey, 1937; Penfield & Rasmussen, 1950): The stimulation of different regions of SI can elicit tactile sensations that are explicitly referred to specific parts of the body (see also Tamè, Braun, Lingnau, Schwarzbach, Demarchi, Li Hegner, Farnè, & Pavani, 2012, for functional magnetic resonance imaging (fMRI) evidence suggesting that SI also integrates somatosensory inputs from both sides of the body). As a consequence, a complete map of the body surface can be seen in SI; this is known as the *somatosensory homunculus* (e.g., Narici et al., 1991; Penfield & Boldrey, 1937; Penfield & Rasmussen, 1950; see Figure 2.4). Interestingly, the relative size of the different portions of SI representing different body parts, is not only a function of the size of the represented body part itself, but also of the sensitivity to tactile stimuli in that area (as also determined by the density of the afferent fibers that innervate it). For example, a larger proportion (relatively-speaking) of the somatosensory cortex is given over to the representation of the hands and lips than to other parts of the body given their relative surface area (e.g., Nakamura et al., 1998; Narici et al., 1991; Penfield & Boldrey, 1937; see also Vartiainen, Kirveskari, Kallio-Laine, Kalso, & Forss, 2009, for the observation that this representation might be altered in patients suffering from chronic pain; see also Chapter 8).

It is important to note that the organization of the somatosensory map in SI is similar to another somatotopic map, the *motor homunculus* found in the precentral gyrus (e.g., Penfield & Rasmussen, 1950). The close somatotopic correspondence between these two maps highlights the important relationship that exists between touch and movement (see Gallace & Spence, 2008a; see also Figure 2.4). For example, the brain areas responsible for the perception of touch on the hands in the somatosensory homunculus are mostly located in front of those areas responsible for hand movements in the motor homunculus. Indirect confirmation of the latter claim comes from Wilder Penfield's original studies (e.g., Penfield & Boldrey, 1937; Penfield & Jasper, 1957; Penfield & Rasmussen, 1950). Penfield and his colleagues reported that at approximately 25% of somatosensory and motor cortical sites, movements and tactile sensations were produced, respectively, by means of direct stimulation of the brain, suggesting once again the existence of close somatomotor functional relationships.

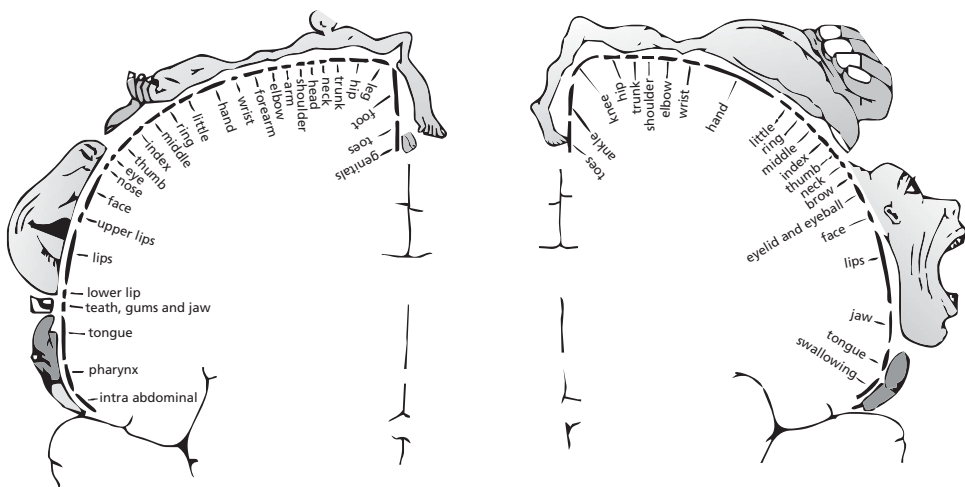


Fig. 2.4 The sensory and motor homunculi located in the postcentral and precentral gyri, respectively.

Despite the fact that inputs from different regions of the body are represented within specific regions of the somatosensory cortex, the cortical maps representing the body are by no means fixed. That is, these maps change between one individual and the next and can be modified by the use of afferent inputs (e.g., Elbert, Pantev, Wienbruch, Rockstroh, & Taub, 1995; Pantev, Engelien, Candia, & Elbert, 2001). For example, early studies on animals demonstrated that if monkeys are trained to perform a given task using only the middle fingers, the areas of the brain representing those fingers become expanded (e.g., Jenkins et al., 1990; Kaas, 1991; Recanzone, Jenkins, Hradek, & Merzenich, 1993). Analogous, but complementary, effects can be obtained by preventing an animal from using a certain body part, or as a result of surgical deafferentation. In this case, it has been found that the area of the brain that before the immobilization/deafferentation responded to stimuli occurring on such a region of the body (e.g., the hand) starts to respond to stimuli presented on other parts of the body that are represented closer to the immobilized part on the somatosensory homunculus (e.g., the face; Bruehlmeier, Dietz, Leenders, Roelcke, Missimer, & Curt, 1998; Jones, Woods, & Manger, 2002). Similar results have been reported using fMRI procedures in humans (e.g., Mogilner, Grossman, Ribraly, Joliot, Wolkmann, Rappaport et al., 1993). For example, a remapping of cortical areas, consisting of an enlargement and increased activation of S1 (as well as M1) area representing the face is consistently found in upper limb amputees after stimulation of the stump (Karl et al., 2001; Ramachandran et al., 1992; see Chen, Cohen, & Hallett, 2002, for a review). That is, S1 would seem to be characterized by a high level of neural plasticity that contributes to an organism's ability to deal with any changes in the amount and/or qualities of sensory inputs arising from our body surface.

The secondary somatosensory cortex (SII) lies adjacent to S1. This area is reciprocally connected with ipsilateral S1 via corticocortical connections (e.g., Burton, 1986; Gardner & Kandel, 2000; Jones, 1986). Evidence from several mammalian species, including non-human primates, suggests the presence of direct thalamocortical projections to SII (e.g., Chakrabarti & Alloway, 2006; Kwegyir-Afful & Keller, 2004; Murray et al., 1992; Rowe & Willis, 1985; Turman et al., 1992; Zhang et al., 2001). Studies in animals have demonstrated that left and right SII cortices have reciprocal connections and the majority of SII neurons display bilateral receptive fields (e.g., Burton, 1986; Caminiti, Innocenti, & Manzoni, 1979; Innocenti et al., 1974; Jones, 1986; Manzoni, Barbaresi, Conti, & Fabri, 1989). Furthermore, SII is reciprocally and somatotopically connected to contralateral S1 (e.g., Barba, Frot, & Mauguire, 2002; Jones, 1986; Manzoni, Conti, & Fabri, 1986). That is, areas of S1 representing a specific part of the body are connected to those areas in SII that respond to the stimulation of the same body part. Note also that both forward and backward reciprocal connections have been documented between S1 and SII (e.g., Manzoni et al., 1986).

Studies in humans using non-invasive (neuroimaging) techniques have confirmed the bilateral projection of the representation of the body to SII (e.g., Simoes, Alary, Forss, & Hari, 2002), and that the somatotopy is less fine-grained than in S1. That is: (1) SII neurons with bilateral receptive fields (e.g., Iwamura, Iriki, & Tanaka, 1994) respond to stimuli presented on both sides of the body; and (2) a somatotopic map (such as the somatosensory homunculus in S1) is also present in SII, but the point-to-point correspondence between body parts and the neural areas where they are represented is not as precise and straightforward as in S1. For example, while the direct stimulation of S1 (say in patients undergoing surgery to treat epilepsy) leads to a sensation that seemingly arises from the hand, a stimulation of adjacent SII leads to a sensation that extends outside the hand area (Mazzola, Isnard, & Mauguière, 2006; see also Burton, Fabri, & Alloway, 1995). In fact, to a large extent, the somatotopic organization

of SII seems to result from the precise, somatotopically-organized projections from SI, rather than from direct thalamic input (such as documented for SI; e.g., Friedman & Murray, 1986; Manzoni et al., 1986).

Much of the existing animal literature suggests that in the initial stages of somatosensory information processing, tactile stimuli that are delivered to one side of the body are first transmitted to the SI and SII cortices contralaterally via thalamocortical connections. After some intrahemispheric integration, this information is then relayed to ipsilateral SI and SII cortices via corticocallosal connections from SI to SI and SII, and from ipsilateral SII to contralateral SII resulting in early interhemispheric integration. Several magnetoencephalographic (MEG) studies have by now reported the reliable activation of contralateral SI and bilateral SII in response to unilateral somatosensory stimuli (Del Gratta et al., 2002; Hari, Karhu, Hamalainen, Knuutila, Salonen, Sams, & Vilkmann, 1993; Lin & Forss, 2002; Mima, Nagamine, Nakamura, & Shibasaki, 1998; Wegner, Forss, & Salenius, 2000) and ipsilateral SI activation has occasionally been observed (e.g., Nevalainen, Ramstad, Isotalo, Haapanen, & Lauronen, 2006; Tan Wuhle, & Braun, 2004).

A number of animal and human studies have investigated (by means of histological sectioning) the somatosensory processing pathways in the brain, illustrating the possible flow of information from early sensory to motor areas (e.g., Friedman, Murray, O'Neill, & Mishkin, 1986). These studies have highlighted the existence of 62 pathways linking 13 cortical areas in the somatosensory/motor system. This compares to the 187 pathways linking 32 cortical areas for vision reported by Felleman and van Essen (1991). Strong connectivity has been demonstrated between areas 3a, 3b, 1, and 2 of SI (see Figure 2.5). At higher levels of information processing, in addition to the already mentioned connections between SI and SII, direct and indirect links have also been documented between both of these areas and Brodmann's areas 5, 6, and 7, the supplementary motor area, the primary motor area, and the granular and dysgranular insula (e.g., Felleman & van Essen, 1991).

Animal studies have also investigated whether or not the flow of somatosensory information from early somatosensory areas to higher order processing areas in the brain occurs in a serial or parallel and distributed manner. A number of studies have demonstrated that the complexity of the receptive field characteristics increases from area 3b to areas 1, 2, and 5 (e.g., Hyvarinen & Poranen, 1978; Iwamura, Tanaka, & Hikosaka, 1980; Iwamura, Tanaka, Sakamoto, & Hikosaka, 1983; Iwamura et al., 1994). It is assumed that this increase in complexity results from the convergence of multiple inputs to single neurons via serial corticocortical connections. This organization would clearly suggest hierarchical/serial somatosensory processing in the postcentral gyrus (e.g., Burton & Sinclair, 1996; see Iwamura, 1998, for a review). The serial organization of this brain area has also been confirmed by anatomical studies (e.g., Felleman & Van Essen, 1991; Künzle, 1978; Vogt & Pandya, 1978). Interestingly, this hierarchical form of information processing has, to a certain degree, also been reported between SI and SII (e.g., Pons et al., 1987, 1992; though see Karhu & Tesche, 1999, for a study documenting the simultaneous early processing of somatosensory inputs in human SI and SII).

It is interesting to note here that the hierarchical organization of connections between somatosensory brain areas seems, in certain respects, to mirror that found in the visual system. Indeed, the nine levels of the somatosensory and motor hierarchy proposed by Felleman and van Essen (1991) in the monkey brain are nearly as numerous as the ten levels of the visual hierarchy, even though fewer than half the number of areas is involved. On the basis of this observation, one might wonder whether similarities in the neural organization of sensory areas might also be suggestive of similarities at the cognitive level of information processing.

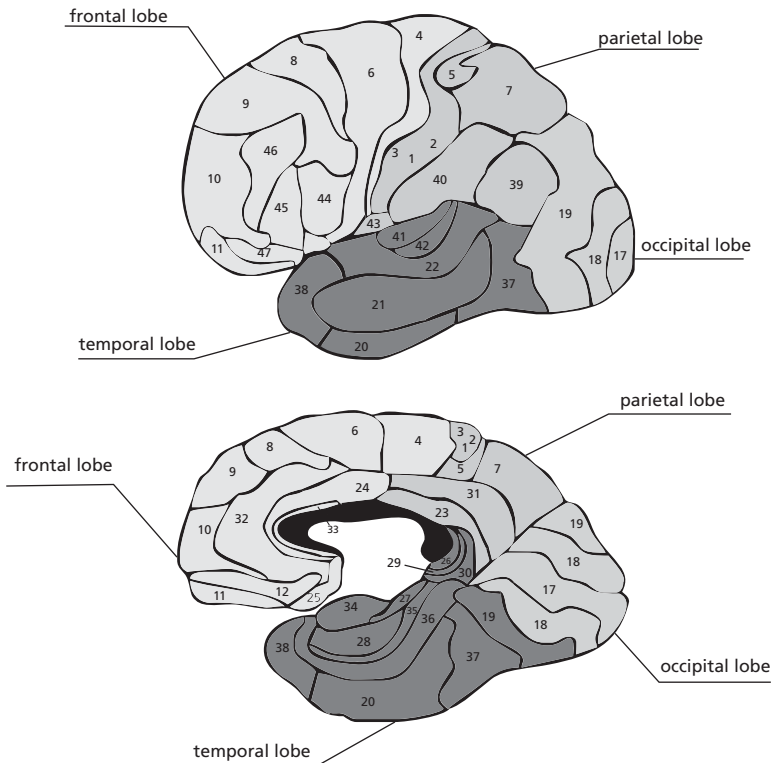


Fig. 2.5 A representation of the Brodmann areas in the human brain.

2.4.2 Bypassing S1: A second pathway for conducting tactile information?

On the basis of the research reviewed here, it should be clear that the initial connections supporting the processing of tactile information appear to be based on a *serial/hierarchical* architecture. Given this observation, one might expect that damage to the primary sensory processing areas should make access to tactile information impossible, even if higher-order structures remain intact. By contrast, damage to the higher-order areas should allow for some sort of computation of tactile information (at least at a less complex level, by means of spared early processing areas).

Here it is important to note that the serial architecture of the neural system underlying the sense of touch has been challenged by the observation of those rare patients affected by damage to the somatosensory cortex. One of the few recorded cases of brain damage confined only to the somatosensory cortex in humans was reported by Brochier and his colleagues (Brochier, Habib, & Brouchon, 1994; see also Halligan, Hunt, Marshall, & Wade, 1996; see Chapter 4). They described a patient suffering from a complete loss of somesthetic sensitivity in his left arm resulting from damage to the primary somatosensory area in the right hemisphere. Interestingly, 2 months after his hospitalization, the patient was able to point correctly to stimulated locations on the affected limb (even if unconscious of their occurrence) when blindfolded, if forced to guess the location in which a stimulus had been presented. In the opinion of Brochier and his colleagues, this unconscious form of sensory information processing, was mediated by an alternative neural

pathway. In particular, they hypothesized that in addition to a neural pathway that projects tactile input from the dorsal column-lemniscal system via the ventro-postero-lateral nucleus of the thalamus (see previous sections), tactile information processing also involves a separate projection from the lateral posterior nucleus to the posterior parietal cortex (areas 5 and 7). Brochier et al. suggested that this channel could bypass the primary somatosensory cortex that the information provided by it was sufficient for controlling the coordinated movement of the deafferented hand. The question then becomes one of whether there is any physiological evidence to support the existence of such a channel in the human brain.

The existence of a pathway that bypasses S1 is certainly controversial. While neurophysiological experiments conducted on certain mammalian species would seem to have confirmed the presence of a channel that bypasses the somatosensory cortex (e.g., Schmammann & Pandya, 1990), the putative existence of such an indirect pathway in humans has only been reported by Martin (1985). He noted that a portion of the medial lemniscal fibers project to the posterior nuclear group of the thalamus, and from here reach directly the posterior parietal cortices. Note, however, that while Martin's report was referenced in the 1985 edition of the highly esteemed *Principles of Neural Science*, edited by Kandel and Schwartz, more recent versions of this volume no longer mention such evidence (see Kandel, Schwartz, & Jessell, 2000, 2012). Even more surprisingly, as far as we are aware, no further studies have been published or cited so far on that topic. Therefore, the putative presence of neural projections from the lateral posterior nucleus to the posterior parietal cortex should remain as a plausible suggestion based on (very little) neuropsychological evidence rather than on neurophysiology (see also Wall & Noordenbos, 1977, for functions that remains intact after complete transection of dorsal columns).

2.5 Conclusions

In this chapter, we have seen that stimuli occurring on and within the body surface (be they mechanical, chemical, proprioceptive, or thermal; see Craig, 2002, for the mechanisms of interoception not addressed in this chapter) are translated by means of different classes of receptors into neural signals. These signals reach, by means of specific neural conductive fibers and via alternative pathways, areas of the brain that are specialized for the processing of different forms of somatosensory information. Importantly, the evidence reviewed in this chapter would appear to suggest that even apparently simple sensations, such as those related to tickling or to the perception of wetness, are actually derived from a form of sensory integration among different sources of information occurring at a number of stages of neural information processing (e.g., Bergmann Tiest, Kusters, Daanen, & Kappers, 2011; Selden, 2004; see also Cappe & Barone, 2005).

The integration of thermal, proprioceptive, mechanical, and/or chemical information shapes our sensations of the outside world whenever we touch (or are touched by) an external stimulus. Interestingly, while certain receptors would seem to be specialized for transducing signals that are germane to the sense of touch (e.g., pressure, slip, flutter), others would seem to be non-specific and codify different sources of information (e.g., pain, proprioception, and gross touch). Moreover, the evidence provided here has highlighted the fact that information about the current status of our body (i.e., the position of the joints and muscles), enters into the complex computations that eventually give rise to tactile sensations; see also Chapter 9, for evidence that bodily movement can result in sensory suppression. That is, the somatosensory system would seem to be based, even at a neurophysiological level, on a neural architecture that is inherently multisensory. As a consequence of these observations, it should be concluded that the differences in the perception of alternative forms of tactile stimuli are unlikely to be strongly related to what actually

occurs at the skin surface, but rather to the central neural networks responsible for processing those signals. In fact, the first stages of tactile information processing would seem to contain relatively unorganized information about the nature of the eliciting stimuli (e.g., the activation of mechanoreceptors alone does not discriminate if we are holding an empty paper glass or a pint of cold lager!).

In summary, the analysis of the earliest stages of somatosensory information processing suggest that the system has evolved with the ultimate aim of generating multisensory “Gestalts” of the component stimuli (see Chapter 3), by integrating information arising from different classes of receptors and submodalities of touch. This aspect related to the physiology of the somatosensory system should be given serious consideration if one’s aim is to artificially reproduce credible and reliable somatosensory sensations. In the chapters that follow, we will analyze what people can actually perceive (and what the laws are that regulate their perception) via their sense of touch on the basis of the neural processing described in this chapter. For example, when talking about tactile completion (see Chapter 3) or tactile illusions (see Chapter 4), we will see that such phenomena are likely related to the general organization of our somatosensory cortex that has been reviewed in this chapter.

Chapter 3

Tactile perceptual organization

Every determinate body has some kind of Gestalt. He who compares the Gestalt of a clod of earth or of a heap of stones with the Gestalts of say a swallow will however at once have to admit that the tulip, or the swallow, has realized the particular genus Gestalt to a greater degree than have the clod or the heap. . . . being of higher as opposed to lower Gestalt . . . can be determined very well by distinguishing marks. Higher Gestalts are those in which the product of the unity of the whole and the multiplicity of the parts is greater.

(C. von Ehrenfels, 1932; quoted in Smith, 1988, p. 123)

3.1 Introduction

From the point of view of a hypothetical non-human observer, information from our world must certainly appear rather chaotic; a plethora of different light and sound frequencies mixed together with a huge variety of chemosensory signals, coming from different positions in space, and reaching our sensory organs at different times or, on occasion, simultaneously. It is our brains' task to try and make sense (that is, to organize) the sensations arising from this complex multisensory environment ("the blooming buzzing confusion" as William James so memorably described the multisensory environment of the newborn human; James, 1890, p. 462) and give them meaning. As far as this organization is concerned, Gestalt psychologists have often suggested that perception is the product of complex interactions taking place among various stimuli performed on the basis of a number of "principles." That is, we can perceive coherent and complete objects or "Gestalts" on the basis of certain laws of perception, that likely operate in all individuals. Note that, despite the lack of interest in the early Gestalt psychologists in the neural substrates of human behavior, it is now clear that many if not all of these laws are shaped on the basis of the constraints laid down by the underlying physiology (see Chapter 2). Understanding these laws, and their roles in the architecture of our neurocognitive systems, helps us to understand how our perception of the world comes about.

The Gestalt grouping principles were originally formulated more than a century ago by researchers working in the field of visual perception (e.g., von Ehrenfels, 1890; Wertheimer, 1912). Extensive research by "Gestalt" psychologists on the topic of unimodal perceptual organization revealed the existence of a number of different grouping principles, such as spatial proximity, similarity, good continuation, common fate (or uniform destiny), closure, and *Einstellung*, that appeared to exert a profound influence on people's perception of the organization of visual

displays (e.g., Koffka, 1935; Köhler, 1930; Smith, 1988; Wertheimer, 1923/1938). In subsequent years, researchers demonstrated that many (if not all) of the Gestalt grouping principles also apply to the auditory modality as well (see Bregman, 1990; Dyson, 2009; Julesz, 1971; Julesz & Hirsh, 1972; Wagemans, *in press*, for reviews). Researchers have even discussed the possibility that the Gestalt grouping principles might be used to help account for the unified perception of the combination of gustatory, olfactory, and tactile stimuli that give rise to the multisensory perception of flavor (e.g., Delwiche, 2004; Spence, *in press*; Verhagen & Engelen, 2006).

To date, however, there has been surprisingly little published research explicitly dealing with the topic of Gestalt grouping in the tactile modality (see Figure 3.1 for a comparison of the number of studies that have investigated the Gestalt grouping principles in vision, audition, touch, and gustation). The topic is mentioned very little (if at all) in the majority of previously published books on touch (e.g., Chatterjee, 2008; Classen, 2012; Field, 2001; Hertenstein & Weiss, 2011). This is particularly surprising given touch's position alongside vision and hearing as one of the "spatial" senses. In fact, until very recently, some of the only examples of researchers actually considering how Gestalt grouping might affect tactile perception came from the early work of David Katz (1925/1989) and Maximilian von Frey (1929). That said, there has been something of a renaissance of interest in this area recently (e.g., see Chang, Nesbitt, & Wilkins, 2007a, b; Harrar & Harris, 2007; Spence, *in press*; Spence et al., 2007), spurred on, in part, by recent developments in the field of tactile/haptic display and interface technologies (e.g., Schiewe, Köhlmann, Nadig, & Weber, 2009; see also Chapter 9). It is interesting to note here that while the majority of the books devoted to the study of visual and auditory perception address the topic of Gestalt grouping (e.g., see Handel, 1989; Moore, 1977; Plack, 2009; Yantis, 2000), contemporary reviews of tactile/haptic perception have typically had remarkably little to say on the topic, either not mentioning it at all, or else mentioning it only very briefly (e.g., Gallace & Spence, 2008a, b; Lederman & Klatzky, 2009; Sonneveld & Schifferstein, 2008).

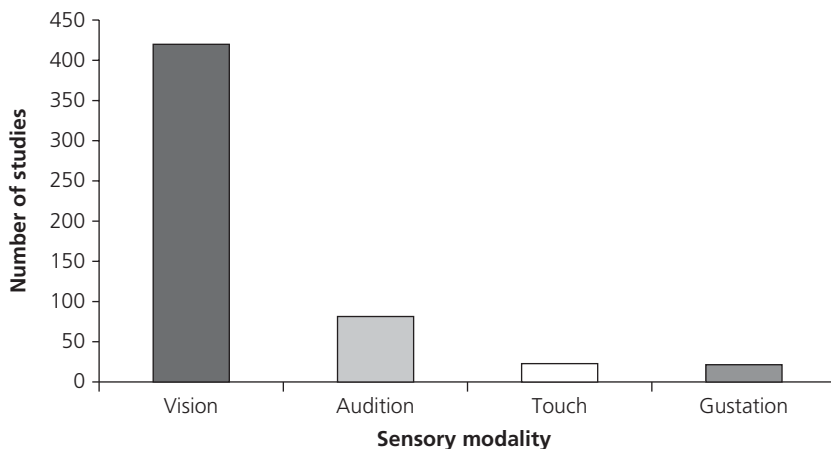


Fig. 3.1 Graph highlighting the number of studies that have addressed topics related to the principles of Gestalt grouping in different sensory modalities. Source Scopus, search performed on October 9, 2012. Parameters of the search: Gestalt OR grouping principles OR grouping AND perception AND: (A) vision OR visual; (B) audition OR auditory OR acoustic; (C) touch OR tactile OR haptic; (D) Flavo(u)r OR gustation OR taste OR olfaction OR smell. The research was performed for words appearing in the abstract.

But should one conclude from this observation that the Gestalt grouping principles are simply not that important in terms of our understanding of tactile perception? We think not. Rather, we believe that the historical lack of published research explicitly devoted to exploring the grouping principles affecting/modulating intramodal *tactile* perception is surprising; it may, at least in part, be related to the difficulty associated with presenting and controlling complex displays that undoubtedly hindered early research in this area. The recent development of new tactile delivery systems has made this potential constraint somewhat less problematic nowadays (see Gallace et al., 2007a, for a review).¹ The lack of interest in tactile Gestalts can also perhaps be traced back to a number of early claims suggesting that the classical Gestalt laws of visual form perception have *no* validity in the haptic (i.e., active touch) modality (e.g., Révész, 1950; Scholz, 1957).

One might also wonder whether the suggestion that Gestalt principles do not affect the tactile modality originates, at least in part, from the fact that touch is often viewed as a sensory modality that requires, at least for the case of object recognition, the serial exploration of the stimulus (e.g., Lederman & Klatzky, 1996; note, however, that the nature of the scanning varies as a function of a participant's expertise with a particular task; e.g., Lappin & Foulke, 1973; Schiff & Foulke, 1982). By contrast, the parallel processing more typically involved in visual object recognition might seem more germane to the immediate grouping of object qualities predicted by the Gestalt grouping principles (e.g., Arnheim, 1956; Koffka, 1935; Köhler, 1930; Smith, 1988).

It should, however, be noted here that even vision, under certain conditions of stimulus presentation (e.g., when using large displays), requires serial exploration (by means of ocular movements) in order to “catch” the meaning of a scene (e.g., Henderson, 2003; Henderson & Hollingworth, 1998; Rayner, 1998). Even more relevant at this point is the fact that the majority of the Gestalt grouping principles have now been found to affect the perception of auditory stimuli, where serial information processing is the norm (e.g., Bidet-Caulet, & Bertrand, 2009; Bregman, 1990; Dyson, 2009; see Julesz & Hirsh, 1972, and see Spence & Chen, 2012, for a comparison of the visual and auditory modalities in terms of the principles of Gestalt grouping).

The fact that active tactile (i.e., haptic) exploration usually requires time-consuming serial scanning is nevertheless still compatible with the idea of tactile representations that are not obtained by the mere sum of partial representations—the very core of Gestalt theory (see Heller & Clyburn, 1993, for a discussion of the question of whether or not tactile perception is based on local or global processing). Finally, it is worth noting that Scholz's (1957) claims regarding the lack of applicability of the Gestalt rules to the tactile modality appear to contrast rather with recent observations that, even in lower mammals, certain adaptive behaviors, such as their response to potential prey (e.g., attack reactions), may be triggered by specific invariant tactile Gestalts (e.g., see Anjum, Turni, Mulder, van der Burg, & Brecht, 2006; see also Anjum & Brecht, 2012).

The fact that certain general laws appear to regulate visual perception in humans has often been taken to suggest that the Gestalt principles are innate rather than acquired (e.g., Di Dio, Macaluso, & Rizzolatti, 2007). On the basis of such considerations, one may certainly wonder *a priori* why these general principles of perception, if innate, should regulate our perception in only a select few of the so-called “higher” senses (namely vision and hearing) rather than for *all* of them (see Metzger 1936/2006, for the early claim that Gestalt laws are “natural” laws and therefore should apply to each and every sensory modality). In fact, a number of studies have now demonstrated that visual and tactile information-processing exhibit more similarities than had previously been thought (e.g., Gallace & Spence, 2008b, for a review; see also Chapter 4).

¹ That said, though, as we will show later in this chapter, Gestalt grouping in the tactile modality can sometimes be investigated (or at least contemplated) using nothing more complex than a coffee mug!

What is more, the recent growth of interest in the study of multisensory information processing (see Bremner, Lewkowicz, & Spence, 2012; Calvert, Spence, & Stein, 2004; Spence & Driver, 2004; Stein, 2012, for reviews) has brought home to researchers the message that perception in everyday situations is rarely unimodal but, nearly always, “multisensory” in nature. Hence, it would be difficult to explain why, if perception is as multisensory as we are now being led to believe that it is, that the Gestalt principles should affect perceptual organization in certain senses but not others (see Kubovy & Yu, 2012). On the basis of these premises, one might even wonder whether or not Gestalt grouping principles act upon “crossmodal” rather than “unisensory” representations. Indeed, Spence et al. (2007; see also Spence & Chen, 2012) have argued that there may well actually be a constant interplay, or tension, between the intramodal and crossmodal grouping of perceptual information in many real-world multisensory scenes/displays.

As far as the tactile modality is concerned, one needs to consider the claim that tactile information processing is much more limited (i.e., affected by different and somehow more stringent constraints than vision), and based on simpler neural circuits than is visual information processing. For example, as we saw in Chapter 2, there are more than twice as many brain areas involved in the processing of visual information as are involved in the processing of tactile inputs (see Felleman & van Essen, 1991). On the basis of such an observation, one might reasonably conclude that automatic principles of organization (perhaps based on innate neural circuits), should more likely affect a sensory modality having a more limited computational power than another with a much higher computational power. In fact, the automatic grouping of stimuli at any stage of information processing ought to prove to be an effective means of preserving cognitive resources for other “later” stages of information processing (see, for example, Lamers & Roelofs, 2007, for evidence that the Gestalt grouping principles affect the deployment of selective attention, and thus participants’ speed of responding in a Stroop task; see also Davis & Driver, 1994). When all of these facts are taken into account, touch seems to be the sensory modality in which computational help (in terms of automatic processing and uncertainty reduction) might be required the most (at least when compared with other spatial senses of vision and audition).

Along similar lines, one may also consider that touch (unlike the other “higher” senses) directly informs the brain about biologically relevant features of the environment by means of our direct contact with the world around us (e.g., Ellis, 1936; Gregory, 1967). As a consequence, the ability to rapidly perceive and respond to tactile Gestalts might well be advantageous from an evolutionary point of view as well (cf. Anjum et al., 2006). At the same time, however, it is also important to remember that there are many important differences between visual and tactile information processing, such as the fact that visual information is coded retinotopically, whereas tactile information is, at least initially, coded somatotopically (see Gallace & Spence, 2008b; Spence & Driver, 2004, for reviews). It would therefore seem highly theoretically relevant to determine whether, and to what extent, the principles outlined by the early Gestalt theorists also apply to the processing of information in the tactile modality.

In this chapter, we will examine a number of different examples of the various grouping principles (such as proximity, similarity, common fate, and good continuation), and how they may (or may already have been shown to) apply to the tactile modality. First, we try to determine the similarities and differences between the results obtained by those studies that have addressed the presence of Gestalt principles in touch with those that investigated the very same phenomena in the visual modality (given that the majority of work on Gestalt grouping principles conducted to date has involved visual perception; see Julesz, 1971; Julesz & Hirsh, 1972; Wagemans, *in press*). Other phenomena that can be related to Gestalt principles in vision, such as subitizing, will be discussed as well. We also highlight the importance of investigating the spatial frame(s)

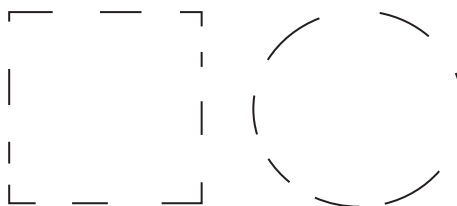
of reference in which Gestalt grouping in touch takes place. We believe that the discussion of this latter point might also help to clarify whether Gestalt grouping principles act at relatively “early” (e.g., at the level of primary sensory areas; or even between stimuli transduced by different classes of tactile receptors; see Chapter 2) and/or “late” stages of tactile information processing in humans. We highlight some of the reasons why the study of tactile information processing may be better suited to answering this question than the study of visual information processing (where it has always been thought that Gestalt principles act at a relatively early stage; see Palmer, 2002, for discussion of this point, and also for evidence that the visual Gestalt principles might actually act at later stages of neural information processing as well). Next, we address the question of the relative strength of intramodal versus crossmodal perceptual grouping under conditions of multisensory stimulus presentation. After all, it is rare that we experience tactile stimulation without some concomitant visual and/or auditory stimulation. Finally, we suggest some important lines for future research in the study of the perception of tactile Gestalts (from both a unisensory and multisensory perspective).

The study of the grouping principles that operate in the tactile modality is extremely timely if one subscribes to the claim that the Gestalt phenomenology may constitute a “powerful tool in search of brain functions” (Ehrenstein, Spillmann, & Sarris, 2003, p. 433; see also Spillmann, 2006; Spillmann & Ehrenstein, 1996, 2003, on the same point; see Wagemans, in press, for but one example of the recent resurgence of interest in this area of research). Improving our knowledge of the phenomena that promote the grouping of tactile stimuli is, though, not only of theoretical interest. It is also potentially of great applied relevance. Indeed, the study of this topic will likely prove critical to the development of effective sensory substitution systems for individuals who are visually impaired (see Spence & Ho, 2008a–d, on this point; see also Chapter 9) and possibly also for the design of more effective tactile (and multisensory) warning signals to be used in cars and other vehicles (e.g., for drivers; see Ho & Spence, 2008; Spence & Ho, 2008a–d; see also Chapter 10). Furthermore, understanding the functioning and fundamental constraints on tactile perception is also particularly important given the recent growth of tactile feedback on everything from touch screens on mobile phones to interactive devices on gaming consoles (e.g., Brewster & Constantin, 2010; Jones, Lockyer, & Piatieski, 2006; Jones & Sarter, 2008; Lee & Spence, 2008; see also Ohka, Takayanagi, Kawamura, & Mitsuya, 2006; Fishel & Loeb, 2012 on the importance of tactile information for the development of robotic systems; see also Chapter 9).

3.2 Perceptual completion

Experimental psychologists have demonstrated that people tend to perceive complete figures even when part of the information is missing (e.g., Kanizsa, 1979; Kanizsa & Gerbino, 1982). This phenomenon, known as “*completion*,” is thought to depend on the Gestalt principle of “*closure*.” Take, for example, Figure 3.2. Here we tend to perceive a circle and a square rather

Fig. 3.2 Examples of amodal completion in the visual modality. The circle and the square are perceived as completing below a number of occluders placed on top of the figures.



than a group of individuated lines. This occurs because we perceptually “complete” the parts of the figure that are physically missing. Researchers have though demonstrated an important distinction between two different forms of completion in the visual modality: Amodal and modal completion. *Amodal* completion occurs when portions of one object are partially occluded by another object, but the former object is nevertheless still perceived as a single continuous entity. Note that, in this case, observers do not actually *see* a contour (i.e., a contrast border) in those regions of the image where completion occurs (e.g., Michotte, Thines, & Crabbe, 1964/1991; amodal completion has also been shown to occur in the auditory modality; see O’Callaghan, 2008, for a review).

By contrast, in *modal* completion, participants perceive an apparently complete shape on the basis of separate inducing fragments. This form of completion is known as “modal” because observers “perceive” an illusory contour even though a real contour is not actually present (the Kanizsa triangle is perhaps one of the best-known examples of this phenomenon; e.g., Kanizsa, 1979; Kanizsa & Gerbino, 1982; see also Spillmann & Dresch, 1995, for a review). That is, as far as the visual modality is concerned, we know that when two visual fragments group together to form an object, the visual system perceives part of the boundary of each fragment as referring to the true boundary of the object. The other part of the boundary is instead perceived as artificial, and as belonging to the boundary of an intervening occluding object. The visual system “hypothesizes” that, at some point, the boundary continues in a way that may not be apparent from image brightness contrast, connecting each fragment to the other. The observer’s perception is therefore of a single object partially hidden by an occluder (see Figure 3.3).

Despite the importance of the phenomenon of completion for visual perception under ecologically valid conditions of stimulus presentation (note that most of the objects that we see in everyday life are partially occluded by other objects or surfaces; cf. von der Heydt, Peterhans, & Baumgartner, 1984), very few studies have directly investigated this topic in touch (e.g., Kennedy & Fox, 1977; Kitagawa, Igarashi, & Kashino, 2009; see also Kennedy & Juricevic, 2006; note that this observation contrasts with the relatively large number of studies that have investigated the cognitive and neural correlates of haptic object recognition and have not mentioned the possible effect of completion on their results; e.g., Bohlhalter, Fretz, & Weder, 2002; Deibert, Kraut, Kremen, & Hart, 1999; Klatzky, Lederman, & Metzger, 1985; Klatzky, Loomis, Lederman, Wake, & Fujita, 1993; Woods, Moore, & Newell, 2008). However, subjective experience would certainly seem to suggest that some form of completion also occurs in the tactile modality.

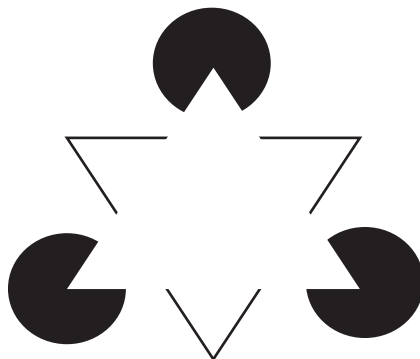


Fig. 3.3 Perhaps the best-known example of modal completion in vision: the Kanizsa triangle (Kanizsa & Gerbino, 1982).

A classic example of completion in an everyday situation was provided by MacKay (1967, 1973): “Suppose I close my eyes and take a bottle in my hand; suppose also that my fingers are spread apart so there are spaces between them. Consider the following tactile analogy of the problem of the blind spot: Why do I not feel holes in the bottle where the spaces are between my fingers?” (see also Kennedy & Juricevic, 2006; O’Regan, 1992). One answer to this question is that the neural representation that we have of this stimulus “completes” the gaps between the individual points of stimulation (see Figure 3.4). However, one should also consider the possibility that a form of amodal completion affects this phenomenon. In fact, if we close our eyes and grasp an object with our fingertips, we do not perceive distinct stimuli associated with each point of contact between our fingers and the object’s surface (the simultaneous stimulation of the fingers would seem to automatically lead to perceptual grouping). Instead, we are able to perceive a unitary pattern of stimulation that belongs to that particular object that we are manipulating (cf. O’Regan, 1992; see also Martin, 1992). That is, we seem to automatically “fill-in” the shape of objects (such as a coffee mug or a pen) that we happen to be holding in our hands. This phenomenon is reminiscent of completion in the blind areas of the visual field (i.e., in the regions where there are no rods or cones; e.g., Sargent, 1988; see Pessoa & De Weerd, 2003, for a review) or in scotomas. In fact, just as for the blind spot in vision, no receptors are present (and thus activated) in the space between the fingers.

Kitagawa et al. (2009) provided some of the first empirical evidence demonstrating the presence of tactile completion. Kitagawa and his colleagues reported that when the brief temporal gaps inserted into a vibrotactile target stimulus (a 200 Hz sinusoidal signal) were filled with vibrotactile noise (a four-octave bandpassed noise centered at 200 Hz; range 50–800 Hz), the target vibration was perceived to continue through the noise (see Figure 3.5). This only occurred



Fig. 3.4 Schematic representation of two possible perceptual interpretations of the same pattern of tactile stimulation. Note that the more “intuitive” interpretation depicted on the left is likely determined by the principles of completion and good form.

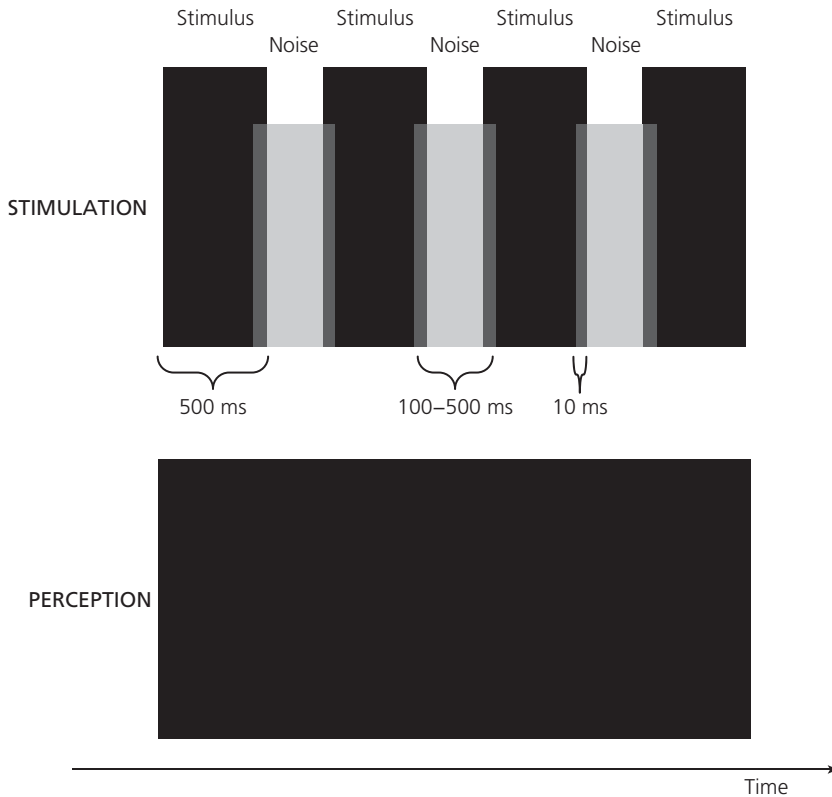


Fig. 3.5 Participants' perception and actual stimuli presented in the study by Kitazawa et al. (2009). Note that the participants feel an illusory continuation of the vibrotactile stimulation whenever the empty gaps between the vibrations presented are filled with tactile noise (see the main text for details).

if the target vibration was sufficiently weak relative to the noise. Even more interesting was the authors' observation that participants could not distinguish the illusory continuity of the vibrotactile stimulus from a physically continuous vibration. This result clearly indicates that under certain conditions of stimulus presentation, people can complete gaps between sequentially presented tactile stimuli. Moreover, the results of Kitagawa et al.'s research would also appear to suggest that it was the "modal" form of completion that was occurring (given that the participants perceived the presence of tactile stimuli between the gaps). Indeed, their participants could not discriminate between the "perceived" (illusory) continuity and the physical continuity of the stimuli. That is, just as in the case of amodal completion in vision, the participants felt the presence of a stimulus with the same characteristics as a real stimulus, even if this stimulation was not physically presented (although it is worth noting that their tactile receptors were stimulated by noise).

Indirect empirical evidence for the presence of completion in touch also comes from an experiment reported by Overvliet, Smeets, and Brenner (2007) designed to investigate whether it is the number of items presented, or the number of fingers stimulated, that determines the duration of

search in a haptic search task. They presented horizontal lines made of swell paper (a kind of heat-sensitive paper that produces raised images when passed through a heat diffuser) to two, four, or six of the participant's fingertips. The participants in their study had to lift the finger under which they did not feel (part of) a line. In one experimental condition, the participants had to find an interruption in a single straight line under one of their fingertips. Overvliet et al.'s participants experienced difficulties when trying to find a line amongst distractors even when they could feel the line endings on both sides of the gaps. It is worth noting here that participants needed significantly more time in which to find the gap than the line itself. These researchers suggested that this result could have been due to the fact that their participants were perceptually "filling in" the gap when the line endings were close together (just as has been demonstrated previously in the visual modality; e.g., Lamote & Wagemans, 1999). This result also supports the claim that completion occurs in the tactile modality.

In summary, it would seem as though the objects that we hold in our hands are recognized (and thus properly used) on the basis of some form of perceptual completion (and hence the Gestalt laws of perceptual grouping are once again seen to apply to the tactile modality). This observation becomes even more interesting if one considers Köhler's suggestion back in the early 1920s that object recognition *involves* the principles of Gestalt grouping (e.g., Köhler, 1920). As he put it, the Gestalt laws "prescribe for us what we are to recognize as 'one thing'" (p. 168). It is even more surprising that, despite the fact that this strong claim was made nearly 100 years ago, only very recently has this topic been put to empirical test in the visual modality (by researchers showing that letter recognition requires the "goodness of continuation"; see Pelli, Majaj, Raizman, Christian, Kim, & Palomares, 2009). We therefore believe that the study of perceptual completion in the tactile modality might offer further evidence in support of the claim that tactile object recognition involves the principles of Gestalt grouping.

Further support for the presence of completion in the tactile modality comes from those studies that have attempted to present visual information via tactile-vision substitution systems (TVSS) to visually-impaired participants (e.g., Bach-y-Rita, 2004; Bach-y Rita, Collins, Saunders, White, & Scadden, 1969). Back in 1970, the wonderfully alliteratively-named Carter Compton Collins suggested the possibility of developing a "*tactile television*," a device that was supposed to be able to convert images into a matrix of tactile transducers placed on a person's back (see Collins, 1970; see also Chapter 9). The tactile stimulators were arranged in a 20×20 array spread over a 10-inch section of the skin of the wearer's backs. The fact that people were apparently able to perceive complete and uniform images using this device, although distinct regions of the skin were stimulated (note that tactile transducers were not placed on parts of the skin that were exactly contiguous, instead, each stimulator was placed approximately 6 mm from the nearest transducer), might be taken to suggest that completion occurs under these conditions of stimulus presentation (see also Kennedy & Fox, 1977).

However, before drawing any firm conclusions concerning tactile completion based on previous TVSS studies there is another important finding that deserves to be discussed here. In particular, from the very beginning of research on this topic, it has been shown that blind participants who have tried to use the TVSS were only able to recognize the visual objects that had been "translated" into tactile images when they were free to actively move the camera used to provide the visual input to the system (e.g., Bach-y-Rita, 1972; Bach-y-Rita et al., 1969; Guarniero, 1974, 1977; Note that this report is reminiscent of Held's (1965) findings that kittens and people can adapt to sensory rearrangement—due to wearing prisms that reverse their visual field (so that what is actually on the left appears on the right and vice versa for what is actually on the right)—only if they can actively move within the environment). This observation would therefore seem to suggest that tactile completion might require the *active* exploration of stimuli. However, the possibility should also

be borne in mind that tactile images might not be created at all. Instead, people might simply extract information from the tactile display and then convert it into visual (in the case of visually unimpaired participants) and/or spatial mental images (e.g., Cornoldi & Vecchi, 2000; Merabet, Thut, Murray, Andrews, Hsiao, & Pascual-Leone, 2004; cf. Sadato, 2005). If this were to be the case, completion in touch might occur at the level of processing at which visual or spatial images are generated in the brain.

Confirmation of the existence of completion in the tactile modality comes from a study by Chang et al. (2007b). They directly investigated the presence of the Gestalt principle of “continuation” in touch. In their study, they presented a number of visual and tactile layouts (see Figure 3.6) and asked their participants to reproduce by drawing the lines of the layout (shapes) that they perceived. They found that many of the participants grouped the haptically-explored elements in such a way that they could be interpreted as continuous lines and forms. This result would therefore appear to suggest that completion affects the perception of tactile information by means of the Gestalt principles of similarity, proximity, and good continuation.

A number of studies conducted over the last three decades have started to shed some light on the neural mechanisms of completion involved in visual perception (e.g., Baumgartner, von der Heydt, & Peterhans, 1984; Eriksson & Nyberg, 2009; Peterhans et al., 1986; Soriano, Spillmann, & Bach, 1996). In particular, it has been reported that the response of neurons in area V2 to a bar

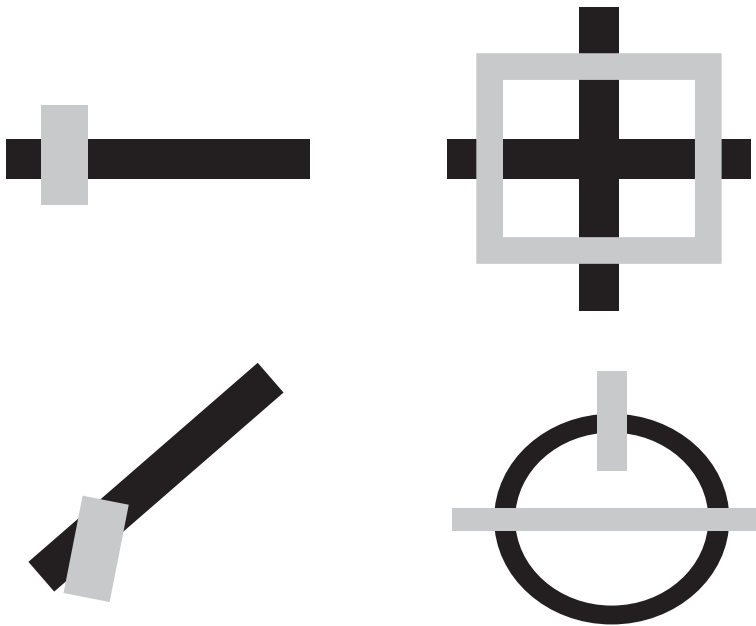


Fig. 3.6 A few examples of the stimuli adopted by Chang et al. (2007b) in order to demonstrate the presence of the Gestalt principle of good continuation in the tactile modality. Light and dark coloring represent two possibilities for grouping within the layout. Note that the dark-colored elements used by Chang et al. (2007b) in their displays were made of sandpaper with a grit value of 120 (rough texture), while the lightcolored elements were made by cardboard (smooth texture). © 2007, IEEE. Reprinted, with permission, from *The Gestalt Principle of Continuation Applies to both the Haptic and Visual Grouping of Elements*, Chang, D., Nesbitt, K.V., and Wilkins, K., Second Joint EuroHaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems.

interrupted by an occluder is qualitatively similar, although somewhat weaker, than the response of the same neurons to a continuous bar (Baumgartner et al., 1984). That is, a neuron will respond even if its receptive field was never stimulated by the traversing stimulus. This result confirms the view that the visual system is capable of restoring an incomplete stimulus. The possible presence of similar mechanisms in the tactile modality seems to be suggested by studies of the “funneling” phenomenon. In this illusion, the simultaneous presentation of brief tactile stimuli at multiple points on the skin produces a single focal sensation at the center of the stimulus pattern, even when no physical stimulus has been presented at that skin site (e.g., Sherrick, 1964). Using neuroimaging, Chen, Friedman, and Roe (2003) were able to demonstrate that the simultaneous stimulation of two fingertips produces a single focal area of activation within an area of the somatosensory cortex that lies between the regions that are normally activated by the presentation of stimuli on each fingertip. It would therefore be interesting for researchers to record activity in SI and SII (see Chapter 2) under those conditions in which participants have been reported to “fill in” tactile information (e.g., Overvliet et al., 2007). This could certainly offer an important contribution to the study of the neural mechanisms of tactile completion.

Interestingly, a parallel has been drawn between filling-in scotomas and the reorganization of the cortical representation of the body in phantom limb phenomena (e.g., Ramachandran, 1993a; Ramachandran & Hirstein, 1998). More specifically, the question has been raised as to whether or not the filling-in of scotomas involves the referral of a sensory representation of the surrounding pattern to the region of the scotoma (see Ramachandran, 1993a). It is worth noting here that in the phantom limb phenomenon, tactile stimuli delivered to the stump of amputated patients are still referred to the position that was previously occupied by the amputated limb (e.g., Weinstein, 1969; see Chapters 4 and 8). It had been thought that this phenomenon was caused by the appropriation of the initial representation of the amputated limb by the afferent input normally directed to the representation of an adjacent cortical areas on the somatosensory cortex (e.g., Pons, Garraghty, Ommaya, Kaas, Taub, & Mishkin, 1991; see also Buonomano & Merzenich, 1998; Merzenich, Recanzone, Jenkins, & Grajski, 1990, for evidence that cortical reorganization follows large-scale changes in incoming inputs regardless of the presence of peripheral lesions). This cortical reorganization requires time, thus ruling out the possibility of its intervention in tactile filling-in. However, other mechanisms (that do not solely involve the reorganization of the somatosensory cortex) might be responsible for the occurrence of the phantom limb phenomenon. In particular, areas of the brain involved in the representation of external space might be responsible for the awareness of tactile stimuli under many stimulus presentation conditions (see Chapter 4). Following on from these observations, one might then wonder whether filling-in in touch should be attributed to the temporary response of neurons that represent the “space” between the stimulated body parts (rather than to the activation of the somatosensory cortex itself; cf. Chen et al., 2003). This speculative hypothesis will certainly need to be carefully evaluated in the future.

3.3 Proximity and similarity

Two further important principles of Gestalt grouping thought to be responsible for the perceptual grouping of visual stimuli are the laws of *proximity* and *similarity* (e.g., Goldstein, 1999; Kubovy, Holcombe, & Wagemans, 1998; Wertheimer, 1923). As applied to visual perception, the principle of similarity states that items that share visual characteristics such as their shape, size, color, texture, value, or orientation will be seen (or perceived) as belonging together (e.g., Goldstein, 1999; Wertheimer, 1923). According to the principle of proximity, items that are closer together will be seen as belonging together (e.g., Goldstein, 1999; Kubovy et al., 1998; Wertheimer, 1923; see

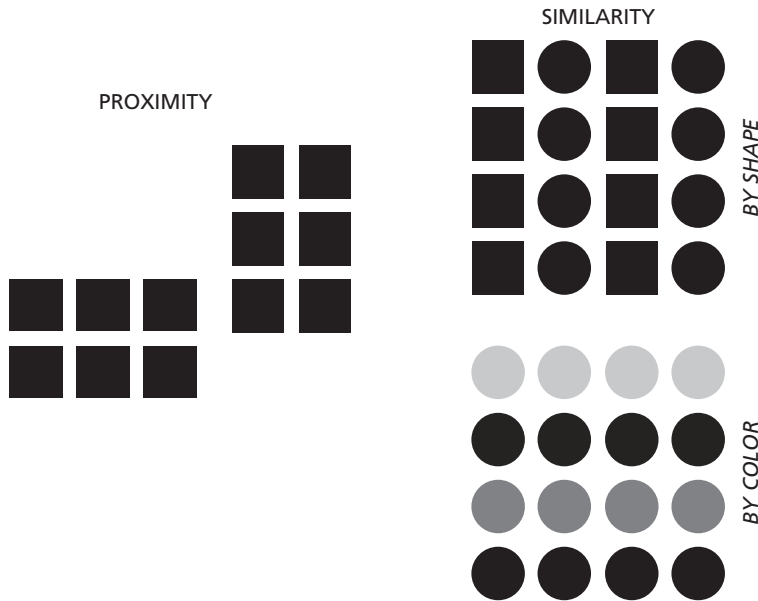


Fig. 3.7 An illustration of the Gestalt grouping principles of visual proximity and similarity. Two examples of similarity (grouping by shape and grouping by color) are represented. Note that different shades of gray in the figure are used to represent different colors.

Figure 3.7). For example, if three dots in an array are closer together than the surrounding dots they will be perceived as a group or even a triangle.

Chang et al. (2007a) investigated whether the Gestalt grouping principles of proximity and similarity would apply to tactile perception in a manner similar to the way in which they have been shown to apply previously to the case of visual perception (see also Spence et al., 2007; Spence & Chen, 2012). The participants in this study had to explore haptic layouts made up of between 7 and 16 elements measuring 2.5×2.5 cm and to group the elements using their hands and fingers while blindfolded. The elements in the layouts differed in terms of their surface texture or inter-item spacing. The participants had to verbally report the number of groups that they perceived. Chang et al.'s results revealed that a significant number of the participants actually used texture to group the elements when there was an equal spacing between them. However, when there was an unequal spacing between the elements, spatial proximity determined the participants' groupings instead. These results can therefore be taken to support the hypothesis that the principles of similarity and proximity are applicable to the case of both visual and haptic perceptual grouping.

3.3.1 Using apparent motion to study the effect of proximity and similarity

The term “apparent motion” refers to an illusion of movement that occurs when two or more adjacent (but static) stimuli are briefly presented, one after the other (e.g., Sperling, 1966). The field of Gestalt psychology gained visibility, at least in part, due to Wertheimer's (1912) early studies of visual apparent motion (see Ellis, 1938; Shepard, 1981, p. 311). The apparent motion experienced by the participants in Wertheimer's studies provided a clear example of an immediate

perceptual experience that did not require reference to any basic constituent features. The principles of grouping apply to the perception of motion given that in order to determine the global motion of an object, the visual system needs to segment and group the local motion signals (i.e., the parts of the stimulus that move synchronously or in the same direction). In order to elicit the perception of apparent motion, a sequence of stimuli must be attributed to the same stream of movement. That is, the object at one location needs to be perceptually related (or grouped) with its existence in a previous location. Similarly, the direction of apparent movement determined by a series of consecutively presented stimuli is thought to be detected only when the stimuli that are consistent with that movement can be grouped together in the same pattern of stimulation (e.g., see Craig, 2003).

Over the years, many studies have demonstrated the existence of an analogous form of apparent motion in the tactile modality (e.g., Geldard & Sherrick 1972; Harrar & Harris, 2007; Kirman 1974a, b, 1983; Lakatos & Shepard, 1997a). In fact, apparent motion is probably the single most intensively studied example of Gestalt grouping in the tactile modality (note that in touch apparent motion can be compared to the “phi” phenomenon in vision where the perception of motion is elicited by a succession of still images; e.g., Wertheimer, 1912). Interestingly, Lakatos and Shepard attempted to investigate whether the spatiotemporal constraints on the perception of apparent motion are similar or different across the various spatial senses. In their study, participants were presented with sequences of visual, tactile, or auditory stimuli from 3, 4, 6, or 12 uniformly-spaced locations arrayed in a circular formation. The participants had to report the direction (one vs. the other) of apparent motion. It is worth mentioning here that somewhat different experimental set-ups were used by Lakatos and Shepard in order to test their participants’ perception of apparent motion in the three different sensory modalities. They presented visual stimuli in the frontal plane in a 10 cm diameter circle viewed at a distance of 75 cm (with the diameter of the circle covering a visual angle of 8°). Tactile stimuli were presented on a circle on the palm of the participant’s hand or around their head (5.6 cm and 23 cm diameter circles, respectively). Finally, the auditory stimuli were presented via a set of evenly spaced loudspeakers arranged in a circular formation around the participant’s head (on a circle having a diameter of 91 cm). Nevertheless, despite these differences in how the stimuli were presented physically, Lakatos and Shepard reported that similar constraints (in terms of the maximum center-to-center distance and stimulus onset asynchrony between successive stimuli whereby the direction of motion could still be perceived) affected the perception of apparent motion in the visual, auditory, and tactile modalities.

Results similar to those of Lakatos and Shepard (1997a) have been reported by Harrar and Harris (2007). They studied the grouping principles at work in the perception of an apparent motion phenomenon known as the *Ternus effect* (e.g., Petersik & Rice, 2006; Ternus, 1926). The stimuli typically used in order to elicit this phenomenon are composed of two sequentially presented frames, which have two distinctly different interpretations (consistent with either element or group motion; see Braddick, 1980), depending on the temporal delay between the onset of the two frames. Harrar and Harris demonstrated that vibrotactile stimuli, just like visual stimuli, can be perceptually grouped in different ways (see Figure 3.8). However, it is important to note that the Gestalt grouping principles in touch were found to be similar, though not identical, to those reported in the visual modality (just as reported previously by Lakatos & Shepard, 1997a). Specifically, different temporal intervals were required in order for group motion to be perceived in the two modalities. In particular, the critical delay at which participants’ perception changed from element to group motion was found to be significantly longer for tactile than for visual stimuli (195 ms vs. 160 ms, respectively).

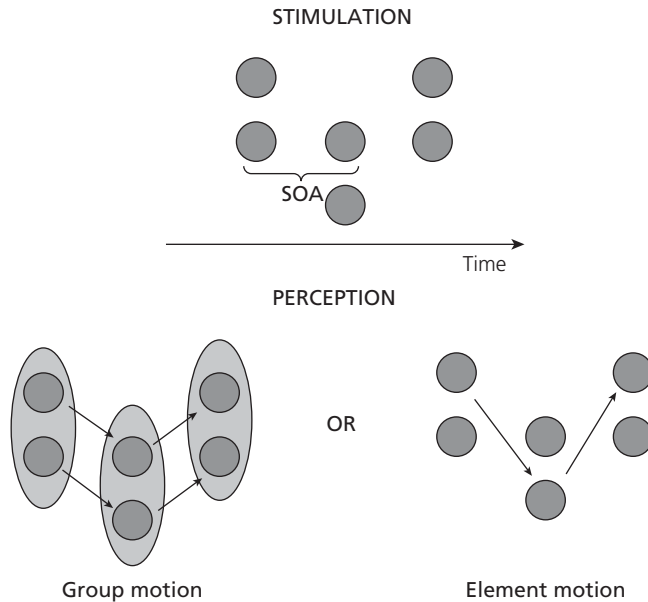


Fig. 3.8 Arrangement of the stimuli adopted by Harrar and Harris (2007) in order to elicit the perception of an unimodal or multimodal Ternus. Note that the participant's perception changes between group motion and element motion as a function of the SOA (stimulus onset asynchrony). Reproduced from *Perception*, **36**, Multimodal Ternus: Visual, tactile, and multisensory grouping in apparent motion, Harrar, V., & Harris, L. R., pp. 1455–1464 © 2007, Pion Ltd, London <<http://www.pion.co.uk>> and <<http://www.envplan.com>>.

In order to interpret this difference, Harrar and Harris (2007) pointed to the fact that stimuli presented in the tactile modality might have a longer persistence than stimuli presented in the visual modality and that the properties of motion-detecting mechanisms in the two sensory modalities might differ (cf. Breitmeyer & Ritter, 1986, for the parameters affecting the Ternus effect in the visual modality). As a consequence of this observation, one might reasonably argue that the differences between the higher-level perceptual organization of tactile and visual stimuli are likely related to lower levels of information processing, rather than to fundamental differences between the two senses at higher stages of information processing.

Researchers have also revealed the presence of “*perceptual rivalry*” in the tactile modality using apparent motion quartets (Carter, Konkle, Wang, Hayward, & Moore, 2008). Perceptual rivalry occurs when stimuli have multiple equally plausible interpretations (e.g., Blake & Logothetis, 2002; Ramachandran & Anstis, 1985; Schwartz, Grimalt, Hupé, Moore, & Pressnitzer, 2012; Zhou & Chen, 2009; cf. Kovacs, Papathomas, Yang, & Feher, 1996, for the role of grouping in binocular rivalry). During visual perceptual rivalry, visual awareness alternates between the perception of one or the other of the two interpretations. For example, by using a display of four dots (known as a “motion quartet”; e.g., Schiller & Carvey, 2006) with two dots in opposite corners (of a square) flashing on-and-off alternately, an observer's perception may fluctuate between the movement of two dots along the horizontal and vertical axes. That is, two stimuli alternately group together, thus affecting people's awareness of a given direction of motion (see Figure 3.9). Using displays composed of four stimuli presented on a participant's fingertip, Carter et al. (2008) reported that the same phenomenon could also be demonstrated when tactile stimuli were presented (with

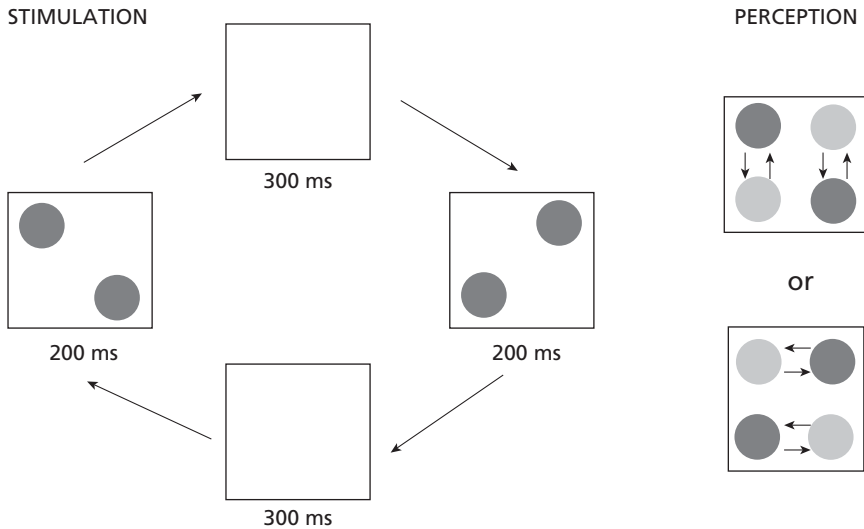


Fig. 3.9 The actual stimuli (left side of the figure) presented in a study by Carter et al. (2008) and the resulting perception of participants (right side of the figure). Note that participants' perception may alternate between one of the two interpretations of movement. Reprinted from *Current Biology*, **18** (14), Olivia Carter, Talia Konkle, Qi Wang, Vincent Hayward, and Christopher Moore, Tactile rivalry demonstrated with an ambiguous apparent-motion quartet, pp. 1050–1054, Copyright (2008), with permission from Elsevier.

participants reporting switches between the perception of motion traveling either up/down or left/right across their fingertip). Once again, these results suggest that similar grouping principles affect people's awareness of information in both the visual and tactile modalities.

To conclude, the evidence reviewed in this section supports the view that the Gestalt grouping principles of proximity and similarity appear to be similar (but importantly, not exactly the same) for vision and touch in the way that they influence the perception of apparent motion in the two modalities (cf. Metzger, 1936/2006). That is, different spatio-temporal constraints appear to affect stimulus grouping in the two sensory modalities, just as has been shown to be the case for the comparison between visual and auditory grouping (e.g., Harrar & Harris, 2007; see also Kubovy & Yu, 2012; Shi, Chen, & Müller, 2009). Whether or not these constraints also affect the *subjective* strength of apparent motion is something that will need to be investigated in future research (cf. Strybel & Vatakis, 2004).

3.3.2 Does Gestalt grouping occur early or late in the processing of tactile information?

Many researchers have already attempted to answer the question of whether grouping occurs “early” or “late” in visual information processing. Often, researchers investigate this question by recording participants' brain activity in response to visual Gestalts, and/or by studying patients with specific brain lesions (e.g., Keil, Müller, Ray, Gruber, & Elbert, 1999; Mattingley, Davis, & Driver, 1997; Schadow, Dettler, Paramei, Lenz, Fründ, Sabel, & Herrmann, 2009; Zion-Golumbic & Bentin, 2007). However, despite the large body of research that has been devoted to this topic, a definitive answer to this question has yet to be reached (see Palmer, 2002; Palmer, Brooks, & Nelson, 2003; Weigelt, Singer, & Muckli, 2007).

One possibility therefore in terms of increasing our understanding regarding the level of information processing at which perceptual grouping occurs relates to the study of the frame(s) of reference involved in the grouping of tactile stimuli. Just as for visual perception, where the position of the stimuli presented in a display can be coded relative to different frames of reference (“retinotopic”—based on the position of the stimuli on the retina; “space-based”—based on the position of the stimuli in external space with reference to the observer’s body midline; or “object-based”—based on the main inner axis of the object itself; see Driver, 1999; Soto-Faraco, Ronald, & Spence, 2004; Spence & Driver, 2004), tactile information can also be analyzed by means of at least two different spatial coordinate systems: somatotopic and space-based.

As far as the sense of touch is concerned, it is worth noting that changing a participant’s posture allows researchers to test the relative importance of the somatotopic vs. spatial frames of reference in tactile information processing/perception (e.g., Craig & Belser, 2005; Kitazawa, 2002; Spence et al., 2008; see also Benedetti, 1985; Corcoran, 1976; and Gillmeister & Forster, 2012, for a recent study on the role of posture on tactile attention; see Chapter 6); for example, when the participant’s hands are held in an uncrossed posture, the two frames of references are coincident (i.e., the “left” according to one frame of references corresponds to the left according to the other frame of reference as well), leading to the most accurate performance. By contrast, when a participant’s hands are held in a crossed posture instead, the two frames of reference conflict (i.e., the “left” hand is now placed in the “right” space), resulting in a worsening of participants’ performance (e.g., Kitazawa, 2002; Röder, Rösler, & Spence, 2004; Yamamoto & Kitazawa, 2001). It is also worth considering that in the tactile system the earliest stages of information processing (at the level of the somatosensory cortex, SI) are based on a somatosensory representation (i.e., a representation that follows the organization of the primary somatosensory area, where different parts of the body are mapped into different parts of the cortex; e.g., Azañón & Soto-Faraco, 2008; Narici, Modena, Opsomer, Pizzella, Romani, Torrioli, et al., 1991; Penfield & Rasmussen, 1950; Sutherland, 2006; see Gallace & Spence, 2010b, for a recent review) while the later stages of information processing appear to be based on spatial (and multisensory/amodal) representations instead (e.g., see Chapter 4; Gallace, Torta, & Iannetti, 2011). These two considerations have allowed researchers to study the level at which grouping takes place in the tactile modality, simply by varying the posture of a participant’s body (usually their arms and/or hands; though see Schicke, Bauer, & Röder, 2009), before or during the execution of certain tasks.

The study of tactile temporal order judgments (TOJs) has revealed that participants’ performance in detecting the order of presentation of two stimuli presented one on either hand is far worse when a participant’s hands are crossed over the midline than when they are uncrossed (e.g., Craig, 2003; Craig & Belser, 2005; Kóbor, Füredi, Kovács, Spence, & Vidnyánszky, 2006; Röder, Rösler, & Spence, 2004; Shore, Spry, & Spence, 2002). This result seems to be related to a mismatch between the primary somatotopic representation of information (especially concerning the notion of left and right) and a later-emerging external representation of space (e.g., Azañón & Soto-Faraco, 2007, 2008; Gallace & Spence, 2008b; Kitazawa, 2002; Wada, Takano, Ikegami, Spence, & Kansaku, 2012; see also Chapter 4). If the Gestalt grouping principles only operate at a higher (i.e., later) level of information processing (requiring a spatial rather than somatotopic representation of stimulus location) one might even expect that crossing the hands should not affect the perception of tactile apparent motion (though see Shore et al., 2002, and Sanabria et al., 2005, for evidence suggesting that the perception of tactile apparent motion is affected by changes in the participant’s posture, just as for the case of tactile TOJs).

Performance in tactile TOJ tasks is affected by the distance (physical or visually perceived) between the two hands (e.g., Gallace & Spence, 2005; Shore, Gray, Spry, & Spence, 2005). That is,

the closer the hands are placed together (or even the closer they visually appear to be placed), the more difficult is to discriminate which of two stimuli delivered one to each hand was presented first. These results have been taken to support the role of higher-order forms of multisensory integration (proprioceptive and tactile, or visual and tactile) in the processing of tactile information (e.g., Gallace & Spence, 2008a, b). Whether or not the distance (be it the physical distance or just the subjectively perceived distance) between the hands affects the grouping and apparent motion of tactile stimuli is therefore another important question, the answer to which should help researchers to determine the level of information processing at which tactile grouping occurs.

Zampini, Harris, and Spence (2005) conducted one of the few studies to have investigated the relationship between a participant's posture and the grouping principle of proximity in the perception of tactile apparent movement. Specifically, they assessed the accuracy of participants' performance in a tactile task (judging the direction in which a pair of vibrotactile stimuli presented to two adjacent digits of either the same or different—interleaved—hands were stimulated) as a function of their posture. They showed that it is not simply the spatial proximity between tactile stimuli that matters, but rather that somatotopic proximity (the distance between body parts as defined by their arrangement on the somatosensory cortex) is also important (see also de Haan, Anema, & Dijkerman, 2012; Haggard Kitadono, Press, & Taylor-Clarke, 2006).

Zampini et al. (2005) reported that when their participants' hands were placed side-by-side, performance in discriminating the direction in which the stimuli moved was very accurate (>90% correct on average). By contrast, when the fingers of their participants' hands were interleaved, performance deteriorated significantly (down to approximately 60% correct). Moreover, this disruption of participants' performance was even more critical for certain specific combinations of stimulated digits than for others (e.g., when the movement of the stimuli across the fingers was toward the left but the second finger stimulated belonged to the right hand, or when the movement was toward the right and the second finger stimulated belonged to the left hand). That is, for a given spatial array of tactors, both the position of the body in space and the specific parts of the body (i.e., limbs) that are stimulated can affect the perceived grouping of stimuli presented over its surface (see Figure 3.10).

Although Zampini et al. (2005) did not explicitly ask their participants to report whether or not they perceived apparent motion, one should consider the fact that a sequence of two consecutive tactile stimuli presented on the body surface can give rise to the phenomenon of apparent motion (e.g., Lakatos & Shepard, 1997a). In fact, the range of stimulus onset asynchronies (SOAs) between consecutive tactile stimuli used by Zampini et al. (i.e., 100–160 ms) fell well within the range in which tactile apparent motion is commonly experienced (e.g., Kirman, 1974a; see also Sherrick, 1964). Therefore, it is possible that Zampini et al.'s participants may well have based their responses on their perception of tactile apparent motion. On the basis of these results, one might conclude that tactile grouping principles, such as those involved in the perception of apparent movement (i.e., proximity, similarity, and good continuation), can operate on both a somatotopic frame of reference (which is not affected by the position of the body in space) and on a spatial frame of reference (which does depend on the position of the body in space). This would also suggest that the perceptual grouping principles might act at both early and late levels of tactile information processing.

However, before a strong claim in support of this conclusion can be made, further investigation of the topic is required. In particular, researchers will need to test directly whether the perception of apparent motion as well as that of tactile displays composed by a number of stimuli is affected by changes in a participant's posture (cf. Sanabria, Soto-Faraco, & Spence, 2005). For example, if participants automatically recognize (or learn to recognize) a square made-up of the stimulation

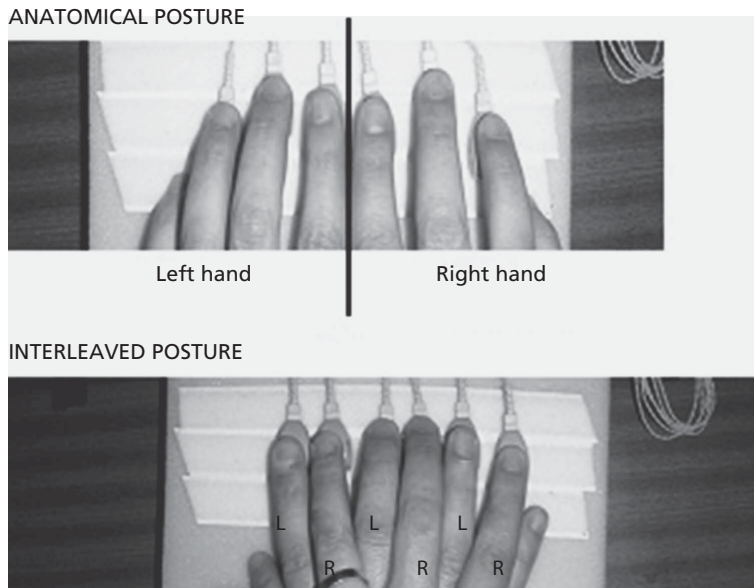


Fig. 3.10 The two postures of participants' fingers used by Zampini et al. (2005) in their study of the perception of tactile movement. Note that when the participant's fingers were interleaved, worse performance was observed. (L = left finger, R = right finger). Reprinted from *Perception & Psychophysics*, **67**, pp. 531–544, Audiovisual simultaneity judgments, Zampini, M., Guest, S., Shore, D. I., & Spence, C. © 2005, Springer Verlag, with kind permission from Springer Science + Business Media B.V.

of four points, two on each limb, would they also recognize the same pattern when they assumed a different posture (e.g., by crossing their limbs over the body midline)? A few examples, taken from the literature on tactile illusions would appear to suggest an affirmative answer to this question. In particular, it has been shown previously that participants report feeling two noses when they touch the tip of their nose with their fingers crossed, a phenomenon known as the “*Aristotle illusion*” (e.g., Hayward, 2008; Rivers, 1894; see also Ponzio, 1910, for evidence that this illusion also works on a number of, how shall we put it, “less-accessible” parts of the male anatomy too). Research in the coming years should more directly investigate the neural correlates of Gestalt grouping in the tactile modality by using electrophysiological and neuroimaging techniques. This approach to the study of the grouping principles in touch has thus far been totally neglected by researchers. We believe that a multidisciplinary approach to the study of Gestalt grouping will help to unravel the neural mechanisms supporting tactile perception.

3.4 The principle of “emergence”: Figure/ground segregation in the tactile modality

According to the Gestalt law of emergence, stimuli are immediately separated from their background in order to facilitate perception (e.g., Peterson & Gibson, 1994; Rubin, 2001). As far as the tactile modality is concerned, common sense would appear to suggest that in order to recognize objects by touch alone, we need to separate them from their background. As soon as an object is placed in our hand, this is physically separated from its background (the only background at

this point being people's awareness of their hand and of the rest of their body). In this case, a neat separation between figure and ground is provided by a person's ability to recognize their body as belonging to themselves. That is, bodily self-awareness might be considered as constituting the most important aspect of figure/ground segregation in touch (see Tsakiris, Constantini, & Haggard, 2008).

It is probably also for this very reason that for a long time researchers haven't questioned people's ability of discriminate their body from the objects that they happen to hold in their hands² (or even of objects that frequently come into contact with their body, such as clothing, glasses, etc.; Holmes & Spence, 2006; Tsakiris et al., 2008). Interestingly, however, a number of studies have now demonstrated that, by using certain procedures, people may feel that an artificial limb (an object somehow resembling their real body) is actually part of their body (see Makin, Holmes, & Ehrsson, 2008, for a review). Even more relevant here is the fact that tools that participants happen to use/manipulate can change the way in which we represent our body (i.e., its perceived length and even its cortical representation; e.g., Cardinali, Frassinetti, Brozzoli, Urquizar, Roy, & Farnè, 2009). These kinds of studies have been discussed elsewhere and thus will not be covered further here (the interested reader is referred to Holmes & Spence, 2006; Makin et al., 2008, for reviews; see also Spence, 2011c). However, here we would simply like to highlight the fact that the results of the extant research on the plasticity of our body representation would seem to suggest that the topic of figure/ground segregation in touch might, at least under certain circumstances, be less trivial than one might have expected (and certainly related to a number of conditions that are peculiar to this sensory modality).

More germane to the topic of figure/ground segregation as identified in studies of Gestalt perception in the visual modality, is the case of objects that lay on a surface (and/or among other objects). In this case, people need to segregate the object haptically from its background in order to pick it up (and use it) properly. Furthermore, the researchers conducting the majority of studies of the haptic recognition of figures have been reluctant to directly link their results to the Gestalt laws (though see Metzger, 1936/2006). This observation may, at least in part, be related to Révész's (1950) early claim that the haptic system is unable to understand interposition or occlusion, perspective and depth, or the cardinal orientations of the vertical or horizontal (though see Heller et al., 2001; Holmes et al., 1998, for evidence refuting this particular claim). Révész even went on to suggest that congenitally blind individuals would have difficulty relating parts to wholes (due to the serial nature of haptic exploration; though see Heller & Clyburn, 1993). Additionally, most of the scientific literature on this topic has dealt with participants who have been blind (e.g., Heller, Wilson, Steffen, Yoneyama, & Brackett, 2003; see also Critchley, 1953, for the claim that blind people perceive Braille in terms of haptic Gestalts).

In most of the studies that can be related to figure/ground segregation in the tactile/haptic modality, researchers have simply studied the ability of people (visually impaired individuals in the great majority of cases) to recognize haptically explored objects (e.g., Heller, 1989a, b, 2000; Heller, Calcaterra, Tyler, & Burson, 1996; Lederman, Klatzky, Chataway, & Summers, 1990; Magee & Kennedy, 1980). These studies have demonstrated that a participant's ability to perform this task varies as a function of the conditions of stimulus presentation (e.g., the amount of time allowed for exploration) and with the nature of the to-be-explored material (with better performance being reported for real objects than for abstract shapes or raised-line drawings; see Gallace & Spence, 2008a, 2009, for reviews).

² Note that the unitary perception of our body might be somehow considered a form of perceptual grouping regarding different sensations arising from inside and outside our skin.

A close link between the study of haptic object recognition and the principles of figure/ground segregation (as highlighted by visual research) comes from those studies that have investigated people’s ability to discriminate certain raised line patterns (the figure) among a group of distractors (the ground; e.g., Axelrod & Cohen, 1961). One such study that directly addressed the question of whether people (visually unimpaired as well as blind participants) can discriminate haptic figures from their ground was reported by Heller, Wilson, Steffen, Yoneyama, and Brackett (2003). There, blindfolded sighted, congenitally blind, late-blind, and very-low-vision participants were tested on a tangible version of the embedded-figures test (see Figure 3.11). The participants in this study first had to explore haptically raised line figures embedded in more or less complex backgrounds (see Metzger, 1936/2006), and then to haptically scan four different figures and select the

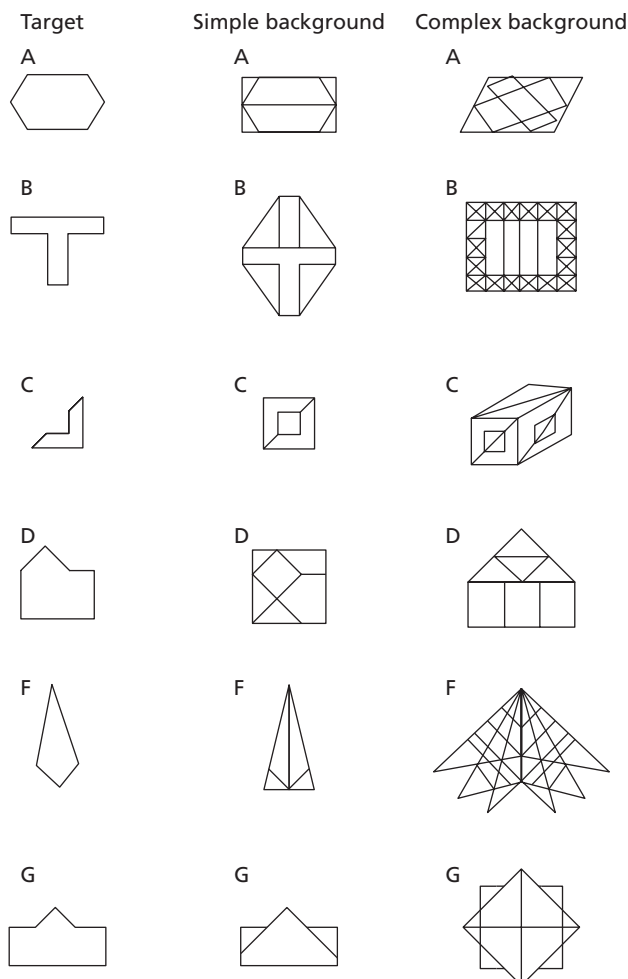


Fig. 3.11 An example of the stimuli adopted by Heller et al. (2003) in their study of haptic raised line figure recognition. Note that the figures could be embedded into either a simple or complex background. Reproduced from *Perception*, **32**, Superior haptic perceptual selectivity in late-blind and very-low-vision subjects, Heller, M. A., Wilson, K., Steffen, H., Yoneyama, K., & Brackett, D. D., pp. 499–511 © 2003 Pion Ltd, London <www.pion.co.uk>.

one that included the target. Finally, the participants had to trace the outline of the target with a pen. The results revealed that the accuracy of the responses of the congenitally blind participants in this task was similar to that of the blindfolded sighted participants, although all of the groups of blind participants performed the task significantly faster than the blindfolded sighted participants (see also Kennedy & Domander, 1984). This result suggests that both blind participants and the visually unimpaired can effectively segregate a tactile pattern from its background.

The ability of sighted participants to segregate a haptic figure from its ground has been investigated directly by Pawluk, Kitada, Abramowicz, Hamilton, and Lederman (2011). These authors asked their participants to estimate the strength of their subjective impression that they were feeling an object (i.e., figure) as opposed to its supporting structure (i.e., the ground) by means of a limited (approximately 200 msec) tactile contact (what the authors named a “tactile glance”). On the basis of the results obtained the authors concluded that at least under the experimental conditions that they adopted, it is possible to segment the figure from the ground by means of a single haptic glance with a “reasonable degree of certainty” (see Pawluk et al. 2011, p. 2).

It is worth remembering that while visual figure/ground separation seems to be performed automatically, the same process requires serial and time-consuming exploratory procedures in the tactile modality. However, under certain conditions, even the visual system can take longer to separate a figure from its ground. A classic example of this concept is the figure of a dog that is often reported in textbooks of visual perception whenever the Gestalt principles (and, in particular, the concept that a figure is not the mere sum of its parts) are discussed (e.g., Marr, 1982; see Figure 3.12). The picture depicts a Dalmatian dog sniffing the ground among snowy patches on a dark ground (e.g., Gregory, 1966). The dog cannot be recognized by first identifying its parts (feet, ears, nose, tail, etc.), and then inferring the dog from those components. Instead, the dog is perceived suddenly as a whole (i.e., all at once). In this case, if the observer has never seen this



Fig. 3.12 The classic picture of a Dalmatian dog sniffing the ground covered by patches of snow often used as a demonstration of the principle of “emergence” in Gestalt psychology. Reproduced from Marr (1982) (p. 101, figure 3-1). Reproduced from Marr D. *Vision. A computational investigation into the human representation and processing of visual information*, p. 101, figure 3.1 © 1982, The Author’s Estate.

picture before, the perceptual separation between the dog and its background can take a long time. However, once the figure has been interpreted it will immediately be perceived on future viewings (just as it has been demonstrated for 3D coherent patterns embedded within random dots displays; e.g., Julesz, 1962, 1971). This example clearly suggests that previous experience with a given stimulus may play an important role in figure/ground segregation for both visual and tactile perception (see Ahissar & Hochstein, 2004). Future research will therefore need to address the role of learning and memory in haptic figure/ground segregation. Researchers will also need to address the neural correlates of the figure/ground segregation in touch (cf. Pizzamiglio & Carli, 1974).

As far as the visual modality is concerned, a number of studies have started to highlight the neural substrates underlying the law of emergence in vision. For example, Baumann et al. (1997) and Zhou et al. (2000) have both reported the presence of “edge polarity neurons” in areas V2 and V4 in the monkey that respond to a light–dark step in one direction, but not in the other. Given the right direction of polarity, this asymmetric response, in conjunction with a closed contour, might underlie the “belongingness” of the border to “the figure” rather than to “the ground.” That is, this mechanism might constitute the neurological basis of figure/ground segregation. Although no study has, as yet, investigated this topic, one might expect the presence of a tactile analog of “edge polarity neurons,” perhaps activated by differences along the dimension of “softness–hardness” or “smoothness–roughness” (i.e., texture) rather than that of “lightness–darkness.”

3.5 Common fate

The law of common fate states that those elements in a display that move in the same direction (or onset/offset at the same time) will be more likely to be perceived as a single unit/pattern. One classic example of common fate is the case of a target figure composed of dots and embedded into a random dot pattern. While the target figure remains static only the random field of dots is detected and the figure remains invisible. However, as soon as the figure moves (all of the dots that constitute it move coherently), it immediately pops-out, that is, it becomes visible. As far as the tactile modality is concerned, very few studies have attempted to investigate whether or not patterns of coherently moving stimuli pop-out from a background consisting of random stimulation. The evidence collected so far has shown that blindfolded human participants can perceive a single object when two cylinders are moved in phase on the volar surface (i.e., on the palm of the hand) of two different fingers (Kitada, Kochiyama, Hashimoto, Naito, & Matsumura, 2003). Similarly, researchers have reported that a moving stimulus (a ball) will pop-out among anchored distractors when explored haptically (van Polanen, Bergmann Tiest, & Kappers, 2012).

Here, it is worth noting that if one also considers movements of the stimuli toward or away from the skin, empirical evidence consistent with the presence of common fate in the tactile modality can also be found in studies of TVSS and Braille terminals for visually impaired individuals (e.g., Bach-y-Rita, 2004; Bach-y-Rita et al., 1969; Collins, 1970; Sriskanthan & Subramanian, 1990).

As mentioned already (see section 3.2 on tactile completion; see also Chapter 9), these devices consist of arrays of tactile stimulators that are in contact with the skin surface (a sort of “tactile static background”). In order to present a given pattern (the outline of an object or a given Braille figure), a number of tactors need to be activated. In this case, the stimuli pop-out from their background and the participants can perceive a given object shape or Braille character. Note that this case might be considered more relevant to the principle of common fate applied to “luminance changes” in vision, where all of the stimuli that change their luminance together are grouped, rather than to common fate by motion (see Sekuler & Bennett, 2001). That is, all of the stimuli moving toward the skin are coherently organized and separated (pop-out) from the static display

that is continuously in contact with the skin (e.g., Critchley, 1953; though note that in Braille reading, serial movements of the fingertips are essential to the correct perception of the stimulus displays). Given that participants can be successfully trained to use these devices, one might assume that common fate also affects the perception of tactile stimuli (cf. Uttal, Spillmann, & Sekuler, 1998; Uttal, Spillmann, Stuerzel, & Sekuler, 2000).

Despite the evidence provided by the studies of TVSS, researchers will certainly need to investigate further whether stimuli moving coherently within displays delivering random tactile stimulation can pop-out from their background and can be easily identified by both blind and sighted participants. One way in which to do this would involve the use of “bi-dimensional” forms of tactile movement (i.e., movement not only occurring toward or away from the skin—i.e., pressure—but across the same plane as the one where the participant’s hands are placed) as well. Moreover, the principle of common fate in touch should not only be investigated by using moving stimuli, but also by varying certain parameters of the stimulation (i.e., by changing the frequency or amplitude of a number of factors and leaving these parameters constant for the other factors within the display).

As far as the neural basis of the principle of common fate is concerned, it has been proposed (e.g., Eckhorn et al., 1990; Singer & Gray, 1995) that coherence is brought about by synchronization of oscillations in neurons “tagged” by a common feature (such as coherent motion). That is, common fate might derive from the neural synchronization of neural activity elicited by a number of stimuli sharing a certain characteristic (e.g., Ehrenstein et al., 2003). Given that neural synchronization has also been reported within the somatosensory cortex (e.g., Murthy & Fetz, 1992; Nicolelis, Baccala, Lin, & Chapin, 1995; Steriade, Amzica, & Contreras, 1996; see also Steinmetz, Roy, Fitzgerald, Hsiao, Johnson, & Niebur, 2000), one might speculate that this mechanism could provide a neurological foundation for the principle of common fate in tactile perception as well. In the study mentioned earlier by Kitada and his colleagues (2004), the authors reported that in-phase stimuli activated the left intraparietal and inferior parietal areas significantly more than did out-of-phase stimuli, leading to the suggestions that these brain areas might be the more likely candidate structures for the principle of common fate in touch to emerge.

3.6 Subitizing and grouping in touch

Subitizing, the rapid “apprehension” of a small number of simultaneously presented items has a long history in the field of experimental psychology (e.g., Atkinson, Campbell, & Francis, 1976; Jevons, 1871; Trick & Pylyshyn, 1993, 1994; see also Chapter 4). Although subitizing has never (as far as we are aware) been explicitly related to the Gestalt grouping principles, an important observation based on this phenomenon should be mentioned here. It has been suggested that the rapid and accurate response concerning the numerosity of a small number of visual stimuli may be due, at least under certain conditions of stimulus presentation, to the fact that people automatically organize these stimuli into patterns (e.g., two stimuli can be perceived as a line, three as a triangle, and four as a square or diamond; e.g., Mandler & Shebo, 1982; note that in visual memory research this phenomenon is also known as “chunking”; e.g., Chase & Simon, 1973; Miller, 1956). That is, the principles of perceptual grouping might well contribute to the phenomenon of subitization.

Support for the latter claim comes from a study reported by Mandler and Shebo (1982) in which the participants were presented with visual displays in which the items were either arranged in a familiar pattern (e.g., such as seen on the face of a dice), or else arranged randomly. The participants demonstrated a pattern recognition advantage in terms of both the speed and accuracy of their responses to the familiar patterns as compared to the random stimulus arrangements. On the basis of these results, Mandler and Shebo proposed that subitizing results from geometric cues in the arrangement of items in the display leading to fast pattern recognition, and thence access to

associated information regarding numerosity. Similar results have also been reported by Wender and Rothkegel (2000). In particular, these researchers demonstrated that when presented with more complex displays, participants will try to partition them into smaller canonical patterns prior to enumeration. That is, enumeration is easier when the elements group in a manner that is conducive to form recognition (e.g., van Oeffelen & Vos, 1982; Vos, van Oeffelen, Tibosch, & Allik, 1988). Taken as a whole, the results of these studies would therefore appear to suggest that subitization might be seen, at least under specific conditions of stimulus presentation, to reflect the consequences of Gestalt grouping.

On the basis of these observations, one might therefore wonder whether or not subitizing also occurs in the tactile modality. Unfortunately, answering this very simple question has turned out to be a good deal more complex (not to say controversial) than might have been expected. Indeed, although several studies have been published on this topic, their interpretation is still the subject of quite some debate (e.g., Gallace, Tan, & Spence, 2006a; Lechelt, 1974; Plaisier, Bergmann Tiest, & Kappers, 2009; Riggs, Ferrand, Lancelin, Fryziel, Dumur, & Simpson, 2006; see Gallace, Tan, & Spence, 2008a, for a discussion of this topic). In particular, on the basis of a study in which multiple (passively presented) tactile stimuli were simultaneously presented across participants' bodies, Gallace et al. (2006a) concluded that tactile stimuli *cannot* be subitized. By contrast, Riggs et al., who presented tactile stimuli to participants' fingertips, came to exactly the opposite conclusion, arguing instead that subitizing *does* occur in the tactile modality.³

Controversial results on the topic of subitizing in touch have also been reported in a number of studies where participants were encouraged to actively explore the stimuli. For example, Plaisier and her colleagues (2009) had participants haptically explore varying numbers of spheres using their hands. The results of this study showed that the enumeration of up to three stimuli was more efficient than for larger numbers of stimuli, leading the authors to suggest that "a haptic version of subitizing exists in active touch" (see also Plaisier & Smeets, 2011; Plaisier, van't Woud, & Kappers, 2011; Plaisier, Bergmann Tiest, & Kappers, 2010). It is, however, important to note here that "subitizing" comes from the Latin word "subitus," meaning sudden. As a consequence, the very idea of a "haptic subitizing," requiring time-consuming serial exploration of the stimuli, might be considered debatable. Despite the different conclusions reached by the studies that have investigated this topic, it is perhaps worth noting that, in both cases, the organization of the display presented was not investigated. That is, it is difficult to determine whether the participants in these studies of tactile numerosity were able to group the stimuli that were presented into meaningful patterns of stimulation (cf. Gallace et al., 2008a; Plaisier et al., 2009; see also Gallace, Tan, Haggard, & Spence, 2008b, for the suggestion that multiple tactile stimuli can be held in short-term storage more easily as patterns than when perceived as multiple independent elements). The fact that people trained to use the TVSS can apparently learn to recognize patterns presented on different parts of their body surface might be taken to suggest this to be the case (e.g., Bach-y-Rita, 2004; see section 3.7; though see Lenay, Gapenne, Hanne-ton, Marque, & Geouelle, 2003, for a critical view of the concept of "substitution" in TVSS research). Note, though, that participants in tactile numerosity studies (in contrast to studies of TVSS) are not typically given extensive practice at the task prior to taking part in the experiment. Therefore, one might expect that the presence versus absence of the subitizing phenomenon in touch can also be determined by the participant's expertise with the task (cf. Lappin & Foulke, 1973).

³ This result has subsequently been attributed mainly to the way in which Riggs and colleagues analyzed their data, rather than to an actual discontinuity between the subitizing and counting ranges (see Gallace et al., 2008a, on this point).

On the basis of the studies on tactile subitizing that have been conducted to date, one may conclude that subitizing in touch, if it exists at all, seems to be limited to a much smaller number of simultaneously presented stimuli than those that limit visual subitizing (e.g., Atkinson et al., 1976; Jevons, 1871; Trick & Pylyshyn, 1993, 1994). However, the fact that no study (of numerosity) has ever made use of patterns with meaning rather than randomly arranged stimuli in order to study the presence versus absence of subitizing in touch, means that it is much more difficult to provide a definitive answer to the question of whether or not this phenomenon affects the perception of tactile stimuli. Future studies should therefore investigate whether (and under what conditions of stimulus presentation; including conditions of serial and parallel stimulus presentation; see Plaisier et al., 2009, 2011) the presentation of variable numbers of tactile stimuli that can, at least theoretically, be easily organized into meaningful patterns (lines, triangles, squares) does, in fact, lead to improved performance. If such a result were to be obtained, it would suggest that certain (to-be-determined) stimulus parameters automatically lead to the phenomenon of perceptual grouping. Whether the organization of tactile information into patterns occurs only on those regions of the skin with a high level of sensory acuity and/or when contiguous areas of the skin are stimulated (see Jones et al., 2006) is another matter that is most definitely deserving of further empirical investigation.

3.7 Grouping and the concept of the “tactile perceptual field”

Visual signals are organized within a defined space, i.e., the “*perceptual field*,” where collections of individual elements are perceived as dots, lines, and edges in order to generate shapes (see Spillmann, 2006, for a review on the link between the concept of the perceptual field and the Gestalt school). Moreover, the visual field provides a space in which individual stimuli can be combined to form spatial patterns. For example, the claim is that within the visual field, two dots will be perceived as a line, three dots as a triangle etc. The size of this field in vision has been estimated using psychophysical procedures (e.g., Spillmann, 1971; Spillmann et al., 1987). These measurements, performed at different eccentricities, yielded values between 5′ (at the fovea) and approximately 3° (in the far periphery).

The presence of a tactile analogue of the visual perceptual field has been described by Serino, Giovagnoli, de Vignemont, and Haggard (2008). These researchers reported that when judging the intensity of a tactile stimulus, their participants’ judgments could be improved by the presentation of irrelevant tactile flankers when the target was positioned on the line joining the flankers in comparison to when the target was offset with respect to the line connecting these points (see also Haggard, Christakou, & Serino, 2007, for evidence showing that seeing the body affects the size of the tactile perceptual field). That is, the fact that the flankers were aligned seemingly biased their participants’ perception of the targets falling on that line. The authors argued that this result supported the idea that the two tactile flankers were perceptually organized into a line, and that this pattern structured participants’ perception of the subsequent stimulus. Put another way, Serino et al.’s suggestion was that tactile stimuli may also be organized within a “*tactile perceptual field*” (see also Haggard & Giovagnoli, 2011, for research supporting the existence of a tactile field, analogous to its visual equivalent). Future research will obviously need to investigate the size of this tactile field and whether or not the size changes as a function of the part of the body where the stimuli are presented (perhaps being smaller for parts of the body that are innervated by a larger number of receptors and larger for less well-innervated body locations, just as reported for the fovea and the periphery of the visual field; e.g., Spillmann, 1971; Spillmann et al., 1987).

Given the suggestion that both the visual and tactile field might be based on “spatial” Euclidean rules (Serino et al., 2008), one might wonder whether or not there are different “fields” for each sensory modality, or whether instead a unified multisensory/amodal field might exist (cf. Blumenfeld, 1936). That is, would two visual stimuli and one tactile stimulus automatically be organized into a triangle as a function of certain conditions of stimulus presentation? And, if the answer of this question should be found to be in the affirmative, would the constraints affecting the organization of visuotactile stimuli act at a low or high level of information processing? These important questions, like so many others in this area, all await future research (see Lin & Kashino, 2012, for the failure to find any grouping of tactile and auditory stimuli over time).

3.8 Grouping in multisensory scene perception

Thus far in this chapter, we have reviewed those studies that have investigated perceptual grouping within just the tactile/haptic modality. This has been the traditional approach in Gestalt research (i.e., to treat each sensory modality as if it were completely independent; though see Gilbert, 1938, 1941; Metzger, 1936/2006; see also Julesz & Hirsh, 1972). However, given that research interest in the last couple of decades has moved toward the mechanisms (and perceptual consequences) of multisensory integration, is it not surprising to find that this field of research has also moved in the same direction.

The fact that we automatically associate a number of different sensory stimuli with the same perceptual object/scene might be taken to suggest that the Gestalt grouping principles ought to apply to conditions of multisensory stimulation as well. A number of studies have investigated the effect of grouping on multisensory perception (e.g., Harrar & Harris, 2007; Harrar, Winter, & Harris, 2008; Huddleston, Lewis, Phinney, & DeYoe, 2008; Lyons, Sanabria, Vatakis, & Spence, 2006; Sanabria et al., 2005; Shi et al., 2009). In particular, in a study by Harrar and Harris (discussed earlier), three stimuli (A, B, C; i.e., a “Ternus” display, see Figure 3.8) were presented using a vibrotactile display. The participants in this experiment had to report whether they perceived AB moving to BC (group motion) or A moving to C (element motion). In the unimodal condition, all of the stimuli were of the same sensory modality (i.e., three lights or three vibrations were presented), while, in the multisensory condition, three pairs of visuotactile stimuli were presented (by means of LEDs and tactors). Harrar and Harris reported that the critical delay, where participants reported their perception changing from group to element motion, was significantly different for the visual and tactile displays (162ms and 195ms, respectively). However, the critical delay for the multisensory display (161ms) was not significantly different from the effects obtained with either the visual or tactile displays. On the basis of these results, the authors argued, once again, that similar rules apply to the grouping of unimodal and multisensory displays (see also Shi et al., 2009, for a recent example of audiovisual grouping in the perception of the Ternus display).

In Harrar and Harris’s (2007) study, the information in the bimodal displays was actually redundant between the two different sensory modalities. That is, all of the stimuli were presented concurrently and from the same position on the participant’s fingers. It is therefore difficult to unequivocally support the claim that the stimuli are only grouped on the basis of movement parameters rather than on the basis of their spatial position. Indeed, the fact that Harrar and Harris obtained similar results using both multisensory and unisensory displays can be interpreted along just such lines. Moreover, Harrar and Harris’s results do not help to clarify whether or not tactile and visual stimuli group together when presented from non-redundant positions. This topic deserves to be investigated further in future research (cf. Huddleston et al., 2008, for an attempt to investigate this using audiovisual displays; Spence, *in press*; Spence & Chen, 2012, for reviews).

The competition between intramodal and crossmodal perceptual grouping has been studied most vigorously for the case of apparent motion. In one study, Lyons et al. (2006) investigated the effects of presenting two or six visual stimuli on their participants' perception of the apparent motion of a pair of tactile stimuli, one presented to either hand. The participants in this study had to determine the direction of a tactile apparent motion stream while ignoring an irrelevant visual apparent motion stream. Lyons and her colleagues reported that the condition in which two concurrent irrelevant visual stimuli were presented impaired their participants' performance on the incongruent trials (i.e., when the direction of apparent motion in vision and touch was opposite; see Figure 3.13) more than that where six visual stimuli were presented (this despite the fact that six stimuli would be expected to be more effective than two stimuli in giving rise to apparent motion).

On the basis of their results, Lyons et al. (2006) went on to conclude that *intramodal* visual perceptual grouping constrained the *crossmodal* binding (the combination of stimulus features that results into an object representation; see Velik, 2012, for a recent discussion on perceptual binding) of visual and tactile apparent motion information. That is, the grouping of visual and tactile stimuli affects the amount of binding between stimuli presented in those two sensory modalities. This result would appear to suggest that multisensory grouping is possible and, what is more, that it is affected by certain parameters such as the “similarity” between the two displays (i.e., the fact that the two displays, although composed of stimuli presented from different sensory modalities, both comprise the same number of stimuli). Here it is worth noting that “similarity” is always likely to be greater for stimuli that happen to be presented within the same sensory modality than for stimuli that happen to be presented in different modalities. That is, in this case, in addition

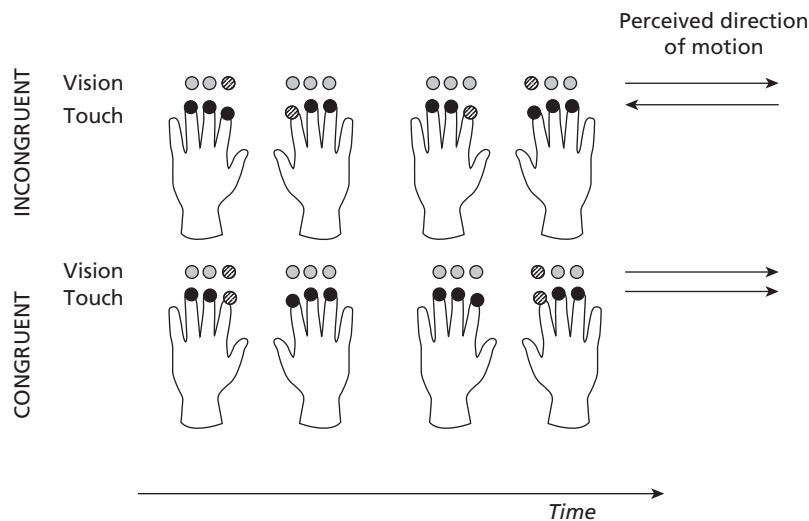


Fig. 3.13 Stimuli utilized by Lyons et al. (2006) in their experiment. Note that participants' performance in discriminating the direction of tactile apparent motion varied as a function of the congruence between the perceived direction of the visual and tactile stimuli. Diagonal stripes indicate the LEDs (gray circles) and tactors (black circles) that are activated. Data from *Experimental Brain Research*, **174** (3), pp. 510–516, The modulation of crossmodal integration by unimodal perceptual grouping: A visuotactile apparent motion study, G. Lyons, D. Sanabria, A. Vatakis, and C. Spence, 2006.

to the other qualities (e.g., spatial and textural), all of the stimuli also share their modality of presentation. On the basis of this observation, one might expect to find that unisensory forms of similarity ought to be stronger than multisensory forms of similarity. By contrast, “proximity” is based simply on the spatial attributes of the stimuli that have been presented. These attributes are shared between different sensory modalities, under various conditions of stimulus presentation (assuming that a common spatial code is used among different sensory modalities; see Chapter 4). In this case, one might expect there to be no differences between grouping based on intramodal and crossmodal proximity. However, one cannot fail to notice that “crossmodal apparent motion” has never been reported before (see Spence et al., 2007; see also Sanabria, Soto-Faraco, & Spence, 2005, and Spence & Bayne, in press; Spence & Chen, 2012, for a discussion of crossmodal apparent motion). This observation might be suggestive of the fact that even spatial proximity is insufficient to override the differences in similarity that must always be present when stimuli are presented to different senses (see Spence, in press).

As far as the topic of figure/ground separation is concerned, a number of studies have used bimodal versions of the Necker cube in order to investigate the interaction between visual and haptic information in the perception of reversible figures (e.g., Ando & Ashida, 2003; Bruno, Jacomuzzi, Bertamini, & Meyer, 2006). In the visual version of the Necker cube (just as for other bistable figures, such as the Rubin vase, that can be perceived as a vase or as a two symmetrical faces; e.g., Rubin, 2001), two interpretations are possible (in this case, a veridical cube or an illusory truncated pyramid). This effect is thought to be related to the fact that the “weight” of two images embedded within the same display is approximately the same, so that it is just as easy to experience each image as either the figure or ground. This illusion has been reported using both visual and tactile displays (e.g., Ando & Ashida, 2003; Shopland & Gregory, 1964).

The participants in a study by Bruno and his colleagues (2006) had to report “reversals” of the visual version of the Necker cube while exploring a haptic version of it. They found that haptic information obtained by moving the hand on the cube tended to make veridical percepts (the perception of a 3D cube rather than that of an illusory truncated pyramid) more durable and consequently reversals somewhat less frequent (see also Ando & Ashida, 2003; Shopland & Gregory, 1964, for similar results). This result clearly suggests that tactile information can modulate the segregation between figure and ground for visual stimuli (see also Lunghi, Binda, & Morrone, 2009). These results might also be taken to suggest that crossmodal interactions occur prior to (or at the same time as) the formation of a perceptual Gestalt. The reciprocal interactions between visual and tactile (and also auditory) stimuli, and, in particular, the relative weight that each sensory modality carries in terms of influencing perceptual grouping is another topic awaiting further investigation.

3.9 Do crossmodal correspondences reflect crossmodal grouping by similarity?

Crossmodal correspondences have been defined as compatibility effects between attributes, or dimensions, of stimuli (i.e., objects and events) in different sensory modalities (be they redundant or not; Spence, 2011d). Crossmodal correspondences have often been documented between continuous stimulus dimensions, such that a more-or-less extreme stimulus on a given dimension in one modality should be compatible with a more-or-less extreme value on the corresponding dimension in another modality. So, for example, increasing auditory pitch tends to be associated with higher elevations, smaller objects, and lighter visual stimuli (e.g., Gallace & Spence, 2006; see Spence, 2011d). What is more, the presentation of crossmodally corresponding pairs of stimuli

often gives rise to a certain feeling of “rightness,” despite the fact that there may be no objective truth about the matter (cf. Koriat, 2008). Finally, crossmodally congruent combinations of stimuli have been shown to give rise to enhanced multisensory integration, as compared to when incongruent pairings of stimuli are presented (see Guzman-Martinez et al., 2012; Parise & Spence, 2012a; see also Sweeny et al., 2012).

As far as tactile stimuli are concerned, a few crossmodal correspondences have been reported in the literature. In particular, small objects are associated with high-pitched sound and judged to be sharp, thin, light, weak, fast, tense, and bright (e.g., Walker & Smith, 1985). Crossmodal correspondences between visual and tactile stimuli have also been reported. In particular, the participants in a study by Martino and Mark (2000) were required to judge the perceived lightness (black vs. white) of a sequence of visual stimuli while ignoring a low- or high-frequency vibrotactile stimulus presented to their fingertips or vice versa (i.e., judge the frequency of vibrotactile target stimuli while ignoring visual distractor stimuli). Their participants responded most rapidly to high-frequency vibrations accompanied by white stimuli and low-frequency vibrations accompanied by black stimuli. That is, high-frequency tactile stimuli would seem to be associated to higher levels of light and low-frequency tactile stimuli to lower levels of light (see also Simner & Ludwig, 2012, for the report that tactile qualities such as smoothness and softness are systematically related to the luminance and chroma of colors). Results such as these clearly suggest that crossmodal correspondences between touch and the other senses exist. They can, perhaps, be thought of as a form of “crossmodal Gestalt grouping by similarity.” This might be the first genuinely Gestalt principle that is specific to crossmodal combinations of stimuli (see Spence, in press).

3.10 Conclusions

In conclusion, we believe that, in contrast to the view espoused by Scholtz (1957) a little over half a century ago, there is no good reason why the Gestalt grouping principles should not be considered as applying to the tactile (haptic) modality, just as they have been shown previously to apply to the visual and auditory modalities. In fact, we would argue that they most certainly do! Contemporary research has now demonstrated that the laws of proximity and similarity affect the grouping of tactile stimuli (e.g., Chang et al., 2007a). These two principles also appear to act upon tactile displays in order to elicit apparent motion in a manner similar to that shown in studies of visual apparent motion (e.g., Craig, 2003; Harrar & Harris, 2007; Zampini et al., 2006). A number of anecdotal observations (e.g., O'Regan, 1992), together with the results of studies of TVSS systems (e.g., Bach-y-Rita, Kaczmarek, Tyler, & Garcia-Lara, 1998; Collins, 1970), and of the few studies that directly addressed this topic (e.g., Kitagawa et al., 2009), also converge on the conclusion that the Gestalt rule of closure might result in the completion of non-contiguous regions of tactile stimulation (e.g., as when we hold an object between the fingers; see Table 3.1).

Determining whether or not a general set of rules applies to our perception regardless of the sensory modality of stimulus presentation certainly sounds like an intriguing challenge for psychologists (see Spence et al., 2007), philosophers (e.g., Epstein & Hatfield, 1994; Spence & Bayne, in press), and neuroscientists (Geisler, Perry, Super, & Gallogly, 2001; Han, Jiang, Mao, Humphreys, & Gu, 2005; Qiu & von der Heydt, 2005; see also Metzger, 1936/2006, for the early suggestion that general rules might apply to every sensory modality; though see Kubovy & Yu, 2012, for the opposite view). However, as yet, and as this review has hopefully made clear, there has been surprisingly little *explicit* interest in the study of the Gestalt grouping principles in the tactile/haptic modality. One might therefore wonder why this important, not to mention interesting, topic has been neglected for so long. One reason that we have already mentioned relates

Table 3.1 The Gestalt laws as reported in vision and their tactile equivalent as emerged from the literature reviewed in the present chapter.

Gestalt law	Definition from studies of visual perception	Equivalence in the tactile/haptic modality
Proximity	Elements that are closer together are grouped together	Tactile elements placed closer together are grouped together (Chang et al., 2007a) Apparent motion can be elicited in the tactile modality on the basis of the proximity of the stimulated elements (e.g., Geldard & Sherrick 1972; Harrar & Harris, 2007; Kirman 1974a, b; Lakatos & Shepard, 1997a)
Similarity	Elements that appear similar will be perceived as part of the same form	Tactile stimuli having the same texture are grouped together (Chang et al., 2007a) Apparent motion can be elicited in the tactile modality on the basis of the similarity of the moving stimuli (e.g., Geldard & Sherrick, 1972; Harrar & Harris, 2007; Kirman 1974a, b; Lakatos & Shepard, 1997a). Note that none of the studies cited here has “directly” investigated the role of similarity in tactile apparent motion, as has been done in the visual modality (e.g., Oyama, Simizu, & Tozawa, 1999)
Good form	A stimulus will be organized into as good a figure as possible, where, “good” means symmetrical, simple, and/or regular	A few examples are provided by Metzger (1936/2006), but no empirical study has ever extensively addressed this topic to date
Emergence (figure/ground segregation)	A stimulus will be perceived as separate from its ground	Common sense suggests that in order to recognize objects by touch/haptics alone (e.g., Heller et al., 1996; Lederman et al., 1990; Magee & Kennedy, 1980) we need to separate them from their ground People can separate figures from their ground when required to haptically explore raised lines figures embedded within tactile displays (e.g., Heller et al., 2003)
Good continuation	Humans tend to perceptually continue contours whenever the elements of the pattern establish an implied direction	Participants have been shown to group haptic elements separated by gaps in such a way that they could be interpreted as continuous lines and forms (Chang et al., 2007b).

Table 3.1 (continued) The Gestalt laws as reported in vision and their tactile equivalent as emerged from the literature reviewed in the present chapter.

Gestalt law	Definition from studies of visual perception	Equivalence in the tactile/haptic modality
Common fate	Elements with the same moving direction are perceived as a Gestalt or unit	The results of studies that have used TVSS and Braille terminals for visually impaired participants suggest that coherent moving tactile stimuli might pop out from a static background (e.g., Bach-y-Rita, 2004; Bach-y Rita et al., 1969; Collins, 1970; Critchley, 1953; Sriskanthan & Subramanian, 1990). A moving stimulus pops-out from amongst anchored distractors when haptically explored (van Polanen et al., 2012)
Closure	Humans tend to enclose a space by completing a contour and ignoring gaps in the figure	TVSS studies suggest that people can perceptually complete information presented in arrays of spatially separated stimulators and perceive closed object (e.g., Bach-y-Rita, 2004; Bach-y Rita et al., 1969; Collins, 1970; see also Kennedy & Juricevic, 2006) People can complete the gaps between two separate sequentially-presented vibrotactile stimuli when these gaps are filled with tactile noise (Kitagawa et al., 2009) The role of visual imagery in tactile closure still needs to be investigated

to the technological limitations associated with stimulating multiple sites on the body surface in the early days of Gestalt research. This limit has now been superseded by the development of new devices that allow one to stimulate multiple bodily locations and to vary independently the intensity of stimulation at each location (see Gallace et al. 2007a, for a review; see also Hayward, 2008, for how a number of tactile illusions can be elicited using very simple and inexpensive set-ups purchased from the local hardware store). We believe that these technical advances will soon pave the way to the more widespread study of Gestalt grouping in touch, the topic addressed by the present review.

A second reason for the neglect probably lies with a number of influential early claims suggesting that Gestalt principles did not affect tactile perception (i.e., due to the serial nature of haptic exploration; e.g., Révész, 1950; Scholtz, 1957). The research highlighted in this review has shown that these claims can no longer be supported and may, in fact, be invalid. In particular, despite the early report by Scholtz that Gestalt principles did not affect the ability of participants to reproduce by drawing haptically apprehended relief copies of the original Wertheimer figures, a number of the more recent studies, reviewed here, have convincingly demonstrated that Gestalt laws do affect tactile perception, even under conditions similar to that used by Scholtz (e.g., see Chang et al., 2007a, b).

In addition to the described reasons, the review of the literature contained in this chapter has also shown a further important reason for this apparent neglect. That is, researchers seem to have been studying questions related to the presence of Gestalt principles in tactile perception without necessarily realizing it. That is, many of the studies summarized in this review never explicitly mentioned the fact that their findings might in some way be explained by specific Gestalt grouping principles (see, for example, the studies of subitizing; e.g., Gallace et al., 2006a, 2007b, 2008a; Riggs et al., 2006; Plaisier et al., 2009, 2011). We believe that, in the future, researchers working on the perception of tactile stimuli will need to be more aware of (and more explicit about) the possible effect that the Gestalt grouping principles may be having on their results, as has been the case for many years in the visual and auditory modalities (see Bregman, 1990; Dyson, 2009; Handel, 1989; Julesz, 1971; Julesz & Hirsh, 1972; Wagemans, *in press*).

In this chapter, we have tried to demonstrate how important the study of the Gestalt grouping principles is to the tactile/haptic modality, not to mention in relation to the growing study of multisensory perception. In particular, in terms of multisensory scene perception in complex multi-item displays, there is likely to be a constant interplay between the ways in which intramodal and crossmodal grouping influence perception (Spence & Chen, 2012; Spence et al., 2007). However, until we develop a better understanding of the principles underlying unimodal tactile grouping, we are unlikely to be able to fully understand (or predict) the nature of any multisensory integration that is taking place in complex multisensory situations (e.g., see Harrar & Harris, 2007; Lyons et al., 2006; see also Spence et al., 2007), comprising those regarding our perception of food (see Chapter 14, for a discussion on the Gestalt grouping of tactile, gustatory, and olfactory cue taking place in the mouth whenever we experience flavors).

We also believe that the future study of Gestalt principles under conditions of unimodal and multisensory stimulus presentation will need to be based on more formal (e.g., mathematical) models (cf. Maloney, Dal Martello, Sahm, & Spillmann, 2005; Wagemans, *in press*; see also Ernst, 2007, for the modeling of crossmodal correspondences). These models should ideally be able to make reliable predictions about a person's perception when two or more grouping principles (and two or more sensory modalities) conflict. (Note that the study of the competition among Gestalt factors has so far been severely hampered by "hysteresis," i.e., the persistence of a given percept despite parameter changes giving rise to stimulus parameters favoring the alternative pattern;

e.g., Ramachandran & Anstis, 1986.) That is, researchers should be able to predict what principle and under what combinations of senses “dominates” over the other, under certain conditions of stimulus presentation (see Ernst & Bühlhoff, 2004; Spence et al., 2007). For example, if a display is composed of a group of stimuli and two of them share the same color but one of the two is closer to a third stimulus (of a different color) will proximity or similarity win the competition for perceptual grouping? At present, there is simply no way of predicting the likely answer to this question a priori.

Finally, one important question to be answered by future research is whether the principle of good form (otherwise known by its German name—“Prägnanz”) also affects the perception of haptically-explored objects. However, before investigating the principle of good form in tactile perception, one needs to answer the more fundamental question of what can be considered “good form” in touch. Answering such questions might well be expected to provide important applied insights for those artists and manufactures who have recently started to use the sense of touch as a form of communication (e.g., see Chapter 9). Moreover, it would be of interest to study the role of attention (that was considered itself a grouping factor by Wertheimer) on perceptual grouping by means of apparent motion using tactile as well as visuotactile displays (see Huddleston et al., 2008, for an example of such a study conducted with auditory and audio-visual displays).

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Section B

Touch in the laboratory 2: Higher-order factors affecting tactile perception

Chapter 4

The awareness of touch

4.1 Introduction

Let's start with a question: Why is it, do you think, that we are aware of information in the outside world? Why can't we just live like zombies, driven directly in our actions by the properties of stimuli and instincts (see Moody, 1994), without necessarily being aware of what happens in our surroundings? Where in our brains does this consciousness regarding the existence of the external world arise? And what are the key differences between those stimuli that enter our awareness thus filling our world with colors, music, caresses, tastes, and perfumes, and those stimuli that fail to reach our awareness, but which may nevertheless still affect our emotions and behaviors? These are certainly not trivial questions. They lie at the boundary between philosophy, psychology, and neuroscience, and many people over the course of the last few centuries have devoted their working lives to trying to answer them. Certainly, though, this quest is still far from reaching a conclusion (and we certainly do not pretend to provide a definitive solution to the problem here). In fact, understanding and explaining the cognitive and neural substrates that give rise to consciousness has been defined by Dehaene and Changeux as the "ultimate challenge of the new millennium" (Dehaene & Changeux, 2004, p. 1145).

Perhaps unsurprisingly, a large and growing research effort has been directed toward the study of the mechanisms underlying the cognitive and neural correlates of *visual* consciousness (e.g., Baars, 1997; Baars & Edelman, 2012; Chica, Paz-Alonso, Valero-Cabré, & Bartolomeo, 2012; Dennett, 1991; Logothetis, 1999; Mattingley, 1999; Singer, 1998; VanRullen & Koch, 2003; see Chalmers, 2000, for a discussion of the definition of the neural correlates of consciousness). As a consequence, most theories of consciousness that have been put forward thus far are, in fact, theories of "visual consciousness" (see Spence & Bayne, in press). Often, these theories do not provide any possibility of being easily extended to account for people's awareness of stimuli presented in the other sensory modalities.¹

In much the same way, most attempts to investigate the neural substrates of conscious information processing have been related to the *visual* awareness of events (e.g., Crick, 1996; Crick & Koch, 1998; Logothetis, 1999; Prinz, 2000; Singer, 1998; VanRullen & Koch, 2003; Zeki & Bartels,

¹ As an example of the visual bias affecting the study of consciousness one may cite Chalmers (1999) in his introductory chapter to the third Tucson discussions and debates regarding the possibility of a "science of consciousness": "Much of the most exciting recent scientific work on consciousness has come from the study of vision. Visual consciousness is in many ways the easiest aspect of consciousness to study: It is ubiquitous, highly structured, it has properties that are easy to articulate, it is relatively easy to monitor, and we have a reasonably good understanding of its basis in the brain" (<<http://cognet.mit.edu/posters/TUCSON3/Chalmers.Vision.html>>). Note that in their seminal paper addressing the neural correlates of consciousness, Crick and Koch (1990) also justify the bias toward the study of visual consciousness by suggesting that the visual system is the "most favorable" in terms of an initial experimental approach.

1998a, b, 1999; see Kim & Blake, 2005, for a review), meaning that the neurological substrate of conscious experiences in other sensory modalities has, with a few exceptions, largely been left unexplored (see Aspell, Palluel, & Blanke, 2012; Auksztulewicz, Spitzer, & Blankenburg, 2012; Berlucchi & Aglioti, 1997; Eimer, Maravita, Velzen, Husain, & Driver, 2002; Palva, Linkenkaer-Hansen, Näätänen, & Palva, 2005; Preißl, Flor, Lutzenberger, Duffner, Freudenstein, Grote, & Birbaumer, 2001; Schubert, Blankenburg, Lemm, Villringer, & Curio, 2006). In this chapter, though, we will try to address this imbalance and move through this largely unexplored territory, where the understanding of our awareness of touch lies.

In order to discuss the many different aspects of tactile consciousness, it is important first to define the object of one's investigation. Consciousness will here be considered as the property of a neural representation of a given piece of information (see deCharms & Zador, 2000, for an extensive discussion of the concept and importance of neural representations in the modern study of neuroscience), of becoming available for explicit report (see Dehaene & Changeaux, 1993; Weiskrantz, 1997).² Therefore, tactile consciousness refers to those aspects of the neural activity elicited by the presentation of tactile stimuli (i.e., be they the result of the activation of one class of sensory receptors located in the dermis or the result of the activation of internal representations without any physical stimulus being presented) that can be explicitly reported. The conscious perception of the interoceptive aspects of sensations, which although neurally and behaviorally linked to the workings of the somatosensory system, will not, however, be covered in any detail here (see Craig, 2002; de Vignemont, Ehrsson, & Haggard, 2005; Katz, 1925; Richer, Martinez, Robert, Bouvier, & Saint-Hilaire, 1993).

Given the apparent relationship between tactile information processing, tactile consciousness, and the representation of the body, we thought it important to briefly highlight the difference between what is commonly known as the "body image" and the "body schema" (e.g., Haggard & Wolpert, 2005; see Holmes & Spence, 2005, 2006; Paillard, 1999, for reviews; see also Heed & Röder, 2012). The term "body image" is typically used to refer to a conscious *visual* representation of the way that our body appears from the outside when viewed in a canonical posture (e.g., Haggard & Wolpert, 2005; Head & Holmes, 1911; Longo & Haggard, 2012). This chapter will not be concerned with the body image, given its visual nature.

By contrast, the "body schema" refers to a postural model that is continuously modified and updated whenever we move or adopt a new posture (e.g., Critchley, 1953; de Vignemont, 2010; Head & Holmes, 1911; Schilder, 1950; see also Haggard, Kitadono, & Taylor-Clarke, 2006). The cerebral bases of the body schema are still unclear, though a central role for the posterior parietal cortex seems likely (e.g., Critchley, 1953; Frederiks, 1969; Mountcastle, Lynch, Georgopoulos, Sakata, & Acuna, 1975; see also Ehrsson, Holmes, & Passingham, 2005a). Note that given the purported importance of the body schema for organizing coherent patterns of bodily movement, it must integrate information from the body surface (provided by the sensory receptors located in the skin) together with proprioceptive information regarding the configuration of the limbs in space. It has been proposed that in order to integrate this information, those stimuli impinging on the body must be transformed from locations on the body surface to locations in external space (see Haggard & Wolpert, 2005; Yamamoto & Kitazawa, 2001; see also Bonda, Petrides, Frey, & Evans, 1995, who have highlighted the involvement of the superior parietal cortex and the intraparietal sulcus in the mental updating of the position of the body in space).

² Note also that the definition used here implies that we are primarily dealing with "access consciousness" rather than "phenomenal consciousness" (see Block, 1995, on this point).

The importance of the spatial aspects of tactile conscious sensation will therefore provide one of the main foci of the research to be described in this chapter. In particular, we hope to show that no comprehensive analysis regarding the awareness of tactile information can be achieved without taking into account the role played by spatial processing and the neural representations that are based on a multiplicity of different spatial frames of reference available to the sense of touch. We also believe that tactile consciousness might reflect a fundamentally unisensory phenomenon (see Spence & Bayne, in press), well differentiated from our consciousness of the stimuli presented in the other sensory modalities. That said, higher-order associative cortices, which have been shown to have multisensory characteristics (e.g., Avillac, Olivier, Deneve, Ben Hamed, & Duhamel, 2004; Pasalar, Ro, & Beauchamp, 2010), appear to be closely involved in our awareness of tactile stimulation (see Gallace & Spence, 2010b).

In this chapter, we will start by trying to answer the question of how extensive the awareness of touch really is. In order to do this, we will try to define the limitations that affect people when multiple tactile stimuli are presented simultaneously: We will briefly summarize the findings regarding “subitizing” in touch, described in Chapter 3. Next we will analyze those situations in which the awareness of touch fails, such as when someone slips the wallet from out of our pocket without being noticed. Then, we will address the problem related to the duration of our awareness of touch and we will discuss the very short period of time, called “the remembered present,” that limits our ability to maintain an active tactile sensation within our perception. In a later section of this chapter, the question of the locus of tactile awareness will be discussed. In particular, we will ask whether our awareness of tactile sensations is limited to the physical extent of our body (as one might intuitively expect), or whether instead, we are aware of sensations occurring in external space, regardless of where our body actually happens to be. After having observed phenomena where people attribute tactile sensations to a pair of stuffed rubber gloves, or to a non-existent arm (as in the case of amputees), or even where they claim to perceive a “saltatory” stimulus moving over their arms when only static stimuli have actually been presented (this is known as the cutaneous rabbit illusion; e.g., Geldard & Sherrick, 1972), the reader will certainly find it less difficult to acknowledge that awareness of touch isn’t limited to the boundaries of our skin! We will then discuss the neurological basis of our tactile awareness by reporting on cases of patients affected by brain damage, and suffering from conditions such as neglect, extinction, and numb-sense, who have lost their ability to report the presence of tactile sensations. Psychophysiological data from experiments on neurologically normal as well as brain-damaged participants will also be provided in order to clarify both the temporal and spatial dynamics of our awareness of touch, as it arises in the brain. Finally, we will conclude the chapter by putting forward a putative neuro-cognitive model that is capable of summarizing all of the data discussed here.

4.2 Numerosity judgments (The “how many” question)

The question of how many objects we can be aware of at any one time dates back to the very earliest days of psychological research (e.g., Hamilton, 1859; James, 1890; Jevons, 1871; Ribot, 1890; Warren, 1897; see also Chapter 3), and even earlier (see Aristotle, ~350 BC, cited in Glanville & Dallenbach, 1929). In particular, Ribot and James first proposed the idea that conscious capacity (what James defined as the “span of consciousness”; James, 1890, p. 405) might be limited. They both pointed out that the contents of consciousness are structured around a *single* “master idea,” or “complex object” or “schema,” thus suggesting that we can be aware of only one structured concept (and/or stimulus) at any one time (note also that Aristotle in ~350 BC asserted that the mind is limited to the consideration of a single object).

4.2.1 Spatial numerosity judgments

One of the first empirical attempts to measure the *visual* span of consciousness was reported by Jevons (1871). He threw a variable number of beans into a box and then tried to estimate their correct number visually in a single glance (note, however, that Jevons did not control for the duration of his visual fixations). Jevons noticed that he was always correct when no more than three or four stimuli had to be counted, claiming that these values might constitute the putative limits on the human capacity of “apprehending” events at any one time. Despite James’s skepticism regarding whether or not these methods can actually tell us anything meaningful concerning the span of consciousness,³ a large body of research has subsequently been dedicated to addressing questions related to the number of stimuli that can enter awareness at any one time (e.g., Atkinson et al., 1976; Fernberger, 1921; Glanville & Dallenbach, 1929; Kaufman, Lord, Reese, & Volkman, 1949; Mandler & Shebo, 1982; Peterson & Simon, 2000; Trick & Pylyshyn, 1993, 1994).

Studies of *visual* numerosity judgments (in which participants are typically required to count the number of stimuli presented simultaneously in a display) have reported differences in both the accuracy and latency of responses when small versus large numbers of items are compared (see Trick & Pylyshyn, 1993). When small numbers of items (typically between one and four) are presented, they appear to be processed very rapidly and in an error-free manner (e.g., Atkinson et al., 1976). When the number of items presented increases above four, a large increase in both average response latencies and error rates is typically observed, giving rise to a discontinuity in the slope of the response latency and error functions. Results such as these have been interpreted by many authors as providing evidence for the existence of two qualitatively different enumeration processes, one specialized for the processing of small numbers of items, the other for processing larger numbers of items. As seen in Chapter 3, the former is known as “*subitizing*” and appears to be fast, accurate, and pre-attentive, while the latter is thought to reflect “*counting*,” and appears to be slow, error-prone, and attentionally demanding (e.g., Kaufman et al., 1949; Mandler & Shebo, 1982; Peterson & Simon, 2000). The investigation of the phenomenon of subitizing by means of the assessment of participants’ performance on numerosity judgment tasks may therefore be seen as an attempt by researchers to explore the often discussed matter of the “span of apprehension” (e.g., Simons & Langheinrich, 1982).

The span of apprehension for tactile stimuli has been studied in far less detail than for visual stimuli (see Gallace et al., 2006a, 2008a) and as we saw in Chapter 3, the results of the studies conducted on this topic lead to controversial interpretations. In fact, while Gallace et al. (2006a) concluded that subitizing does *not* occur for simultaneously presented tactile stimuli, Riggs et al. (2006) came to exactly the opposite conclusion. It is, however, important to note here that Riggs et al. reported a per-item increase in RTs of 260 ms/item within the subitizing range. This value roughly corresponds to the time needed for a young adult to count visually presented objects sequentially while pointing at them with their fingers (e.g., Camos, Barrouillet, & Fayol, 2001). As such, it is difficult to exclude the possibility that Riggs et al.’s participants might have been “counting” the number of their fingers that had been stimulated, rather than “apprehending” them simultaneously (see Gallace, Tan, & Spence, 2008a, for further discussion of this point).

³ “It is obvious that such observations decide nothing at all about our attention, properly so called. They rather measure in part the distinctness of our vision—especially of the primary-memory-image—in part the amount of association in the individual between seen arrangements and the name of numbers” (James, 1890, p. 407).

By contrast, on the basis of Gallace et al.’s (2006b) results, one might conclude that humans are clearly and unambiguously aware (i.e., their explicit detection performance is virtually errorless) of only *one* tactile stimulus presented on a particular body location at any one time. It is important to note here that these two studies of tactile numerosity judgments differed in terms of where the stimuli were presented on the participants’ body: Gallace et al. presented vibrotactile stimuli to a variety of different locations across the body surface, including the legs, arms, waist, and back, while Riggs et al. (2006) presented tactile stimuli on the fingertips instead. It might be possible, therefore, that any putative difference between the results of these two studies could be related to the fact that most people are presumably simply much more practiced at discriminating tactile stimuli using their hands (as in Riggs et al.’s study) than using other parts of their body surface (as for the participants in Gallace et al.’s study; cf. Franz, 1913).

Indeed, it is well-known that a relatively larger proportion of the somatosensory cortex is given over to the representation of the hands than to other parts of the body, given their relative surface area (e.g., Nakamura, Yamada, Goto, Kato, Ito, Abe, et al., 1998; Narici, Modena, Opsomer, Pizzella, Romani, Torrioli, et al., 1991; Penfield & Boldrey, 1937), and that practice in performing specific tasks leads to significant improvement in tactile sensitivity for a given body site (cf. Kóbor, Füredi, Kovács, Spence, & Vidnyánszky, 2006; see Hodzic, Veit, Karim, Erb, & Godde, 2004, for the neural correlates of tactile improvement following practice in humans, as measured by fMRI).

These observations could also be taken to suggest that the number of tactile stimuli that a person can be aware of at any one time might be related to the proportion of cortical surface involved in the representation of the stimuli presented. Baron and Pelli (2006) have reported that when the to-be-counted visual stimuli were placed in the periphery of the visual field (i.e., in a part of the visual field that is less well represented in the brain relative to the fovea; e.g., Masland, 2001) the accuracy of participants’ numerosity judgments decreased even within the subitizing range. Such decrements in accuracy were especially prominent under those conditions where the other distractors were presented together with the relevant stimuli (i.e., a condition known as “crowding”; e.g., Cavanagh, 2001; Flom, Weymouth, & Kahneman, 1963). If confirmed, this result would support the view that the span of conscious perception might be related to the size of the representation in those cortical networks involved in the processing of the relevant stimuli.

Importantly, as seen in the last chapter, researchers have demonstrated that a process similar to subitizing might also occur for stimuli that are actively explored with the hands (e.g., Plaisier et al., 2009, 2010; see Chapter 3). However, as previously mentioned, rather than being interpreted in terms of differences in the cortical representation of the hands as compared to the rest of the body, this result might be related to the fact that more time is given over to the serial exploration of the stimuli (as compared to when they are presented simultaneously; see Javadi & Aichelburg, 2012, for evidence that there is a correlation between the accuracy of visual numerosity judgments and the duration of stimulus presentation). That is, in this case, the procedures adopted might not be adequate to provide information regarding the actual span (in terms of stimuli that can be processed simultaneously) of tactile consciousness.

However, before drawing any firm conclusions on the basis of the results of the extant studies of tactile numerosity judgments, one should perhaps also take a moment to consider whether or not subitizing and counting really do constitute two independent and separate psychological phenomena, as has been suggested by the majority of researchers working on the topic of numerosity in vision (e.g., Trick & Pylyshyn, 1994). This issue is of considerable importance with regard to the question of whether or not the conscious perception of multiple tactile objects is possible at

any one time and if it requires separate mechanisms/substrates in the brain as compared to other forms of sensory information processing. Note that over the years a number of researchers have suggested that the two processes (subitizing and counting) might not necessarily be different in nature, but may rather simply reflect a continuum along a scale of increasing task difficulty (e.g., see Balakrishnan & Ashby, 1991, 1992; Piazza, Mechelli, Butterworth, & Price, 2002; see Burr, Turi, & Anobile, 2010; Gallace et al., 2007a, 2008a, for discussion of this point). Whatever the resolution to this theoretical debate regarding the putative existence of a subitizing effect in sensory perception turns out to be, it is worth noting here that when the results from visual and tactile studies of numerosity judgments are compared, some potentially important differences nonetheless still arise.

Specifically, subitizing has been reported to occur for up to three (e.g., Atkinson et al., 1976; Chi & Klahr, 1975), 4 (e.g., Klahr & Wallace, 1976; Trick & Pylyshyn, 1994), or even five stimuli (see Simons & Langheinrich, 1982) presented in a visual display (note that Kashino & Hirahara, 1996, using auditory stimuli consisting of voices, reported that participants' counting performance deteriorated substantially whenever three or more voices were presented). By contrast, the results of the studies reported by both Gallace et al. (2006a) and Riggs et al. (2006) suggest that subitizing in touch might actually be present for no more than one to three stimuli in a display. Note also that in contrast to the reports that have emerged from studies of visual enumeration, performance in the tactile counting task was not perfect (at least when the stimuli were presented simultaneously rather than explored haptically; cf. Plaisier et al., 2009, 2011; see also Chapter 3), and, to a certain extent, was time-consuming, even within the subitizing range, when the stimuli were presented to participant's fingertips (Riggs et al., 2006).

Finally, it is worth noting that results reported by Gallace, Tan, and Spence (2007b), under conditions of bimodal (visuotactile) stimulus presentation rather surprisingly showed that participants' numerosity judgments for displays composed of a mixed array of visual and tactile stimuli are significantly worse than would have been predicted on the basis of their performance on unimodal numerosity judgment trials. That is, the accuracy of participants' counting of the number of stimuli presented in a given display (regardless of their sensory modality of presentation) was not predicted by participants' performance when the stimuli were presented in unimodal stimulus displays. This result might be the consequence of a sort of multisensory extinction occurring between stimuli presented in different sensory modalities (e.g., Hartcher-O'Brien, Gallace, Krings, Koppen, & Spence, 2008; see also Werkhoven, van Erp, & Philipp, 2009; see Spence, Parise, & Chen, 2011, for a review). Such results also suggest that if numerosity judgments highlight a limitation in the amount of information that people can be aware of at any one time, this limit appears to be multisensorially (rather than unisensorially) constrained (e.g., Gallace et al., 2007a, see also Gallace et al., 2008b; though see also Barth, Kanwisher, & Spelke, 2003). That is, the amount of information that can enter consciousness when stimuli are presented via the skin, might be influenced by the amount of *visual* (and possibly also auditory) information that happens to be being processed concurrently. Moreover, it seems clear that when the information that is carried by two (or more) sensory modalities is redundant, access to consciousness for the one that requires a response may be prioritized (cf. Spence & Parise, 2010; Spence, Shore, & Klein, 2001b). By contrast, when the two sensory modalities carry non-redundant information, and/or a participant's responses to them are dissociated (such as when the stimuli in the two modalities require independent responses) severe limitations or delays in the access to consciousness may arise (e.g., Hartcher-O'Brien et al. 2008; Hartcher-O'Brien, Levitan, & Spence, 2010; Sinnett, Soto-Faraco, & Spence, 2008; see also Gallace et al., 2008a, b, on this point).

4.2.2 The perception of simultaneity and temporal numerosity judgments

A wave of research interest has emerged in recent years regarding the question of how conscious perception evolves over time following the presentation of a stimulus (e.g., VanRullen & Koch, 2003). In particular, many researchers have been interested in the *temporal* as well as the previously well-studied *spatial* characteristics of our awareness. When one looks at the temporal aspects of consciousness, two very different possibilities have been put forward: (1) Neural representations evolve continuously over time and consequently our awareness of events can be thought of in terms of a continuous stream; and (2) We consciously experience the world as a discreet sequence of events, like a series of snapshots each of variable duration (e.g., VanRullen & Koch, 2003; Zeki & Bartels, 1998).

Studies using visual displays have revealed that a minimum interstimulus interval is required between two consecutive events in order for them to be perceived as sequential, rather than as simultaneous. That is, events separated by no more than 20–50 ms tend to be judged as simultaneous, at least when no specific attentional manipulations are performed (e.g., Hirsh & Sherrick, 1961; Kristofferson, 1967; Zampini et al., 2005; though note that in audition pairs of sounds can be perceived as non-simultaneous when separated, at least under certain conditions, by no more than 1 ms; Hirsh & Sherrick, 1961). Moreover, it has been reported that the maximum rate at which participants can count visual stimuli sequentially presented is around 10/12 items per second (e.g., White & Harter, 1969). These results are therefore compatible with the view that stimuli falling within a frame (or temporal window) of approximately 100 ms are consciously interpreted by the brain as constituting a single event, thus supporting the theory that conscious visual perception might be a discrete, rather than continuous, phenomenon (e.g., VanRullen & Koch, 2003; see also White & Cheatham, 1959).

Interestingly, studies of tactile TOJs (see Chapter 3), where participants have to try and determine the correct order of presentation of consecutive stimuli, have highlighted the fact that the maximal interstimulus interval between two events in order for them still to be perceived as simultaneous on a majority of trials is around 40–60 ms (depending on the condition of stimulation—unimanual or bimanual—the body posture—hands close or hand far apart—and finally of the temperature of the body; e.g., Axelrod, Thompson, & Cohen, 1968; Geffen, Rosa, & Luciano, 2000; Röder, Rosler, & Spence, 2004; Shore, Gray, Spry & Spence, 2005; Shore et al., 2002; see also Takahashi, Kansaku, Wada, Shibuya, & Kitazawa, 2013, for the neural bases of tactile TOJs). Under certain conditions of stimulus presentation (i.e., when the stimuli from the two sensory modalities are presented from the same spatial position), this time window appears to be of a similar width to that reported using visual displays, perhaps suggesting a common basis for the temporal qualities of conscious experiences in different sensory modalities (e.g., Hirsh & Sherrick, 1961; Kristofferson, 1967; Poppel, 1988; though see also Spence et al., 2001b, 2003).

In studies of temporal numerosity judgments, participants have to try to count the number of stimuli presented sequentially to a particular body site (normally the fingertips; Lechelt, 1974, 1975; White & Cheatham, 1959). For example, in one such study, Lechelt (1974) reported that numerosity judgments for sequentially presented tactile stimuli were linearly related to the number of stimuli that happened to be presented. Furthermore, the slope of the function fitting the data was influenced by the rate of stimulus presentation (i.e., with performance starting to decrease noticeably as the rate of stimulus presentation increased above 12 stimuli/sec). Interestingly, this result appears very similar to that obtained under conditions of visual stimulus presentation, once again suggesting that the awareness of successive tactile events might be constrained by

a temporal window of approximately 100 ms, just as in the visual modality (e.g., Lechelt, 1975; White & Cheatham, 1959). Unfortunately, however, no study has as yet been conducted on temporal numerosity judgments for tactile stimuli presented from locations other than the fingertips and perhaps even from more than one location (sequentially) across the body surface. The results of such research would likely provide useful information with regard to the question of whether or not the same temporal constraints as those obtained by presenting the stimuli on the fingertips should also be expected under such conditions of stimulus presentation.

It is important to note that the limit of 12 stimuli/sec in the temporal discrimination of visual, tactile, and auditory stimuli occurs after binocular fusion, and therefore at a stage of information processing that lies beyond V1 (e.g., Andrews, White, Binder, & Purves, 1996; White & Cheatham, 1959; White, Cheatham, & Armington, 1953). This observation (i.e., a common limit across sensory modalities) suggests that the temporal constraints on tactile consciousness might not be related to peripheral sensory mechanisms, but rather to more central stages of information processing instead. With regard to this point, it has been proposed previously that “there is some temporal process in the central nervous system that limits and orders the perceptual events of major sense modalities” (White & Cheatham, 1959, p. 444; see also Hirsh & Sherrick, 1961). That is, some researchers have suggested that the time window of consciousness (i.e., the duration of our awareness) for all sensory modalities (or at least for the spatial modalities of touch, vision, and audition) might be determined by the same neural mechanisms (cf. Poppel, 1988).

In vision, it has been suggested that cortical and thalamocortical oscillations in different frequency bands might provide the neural basis for such discrete processes in conscious perception (e.g., VanRullen & Koch, 2003). That is, a person’s awareness of a given stimulus can be influenced by the stage of the on-going alpha electroencephalogram (EEG) cycle at which the event takes place. Indeed, when two successive visual stimuli are separated by a phase of 180 degrees (with respect to the on-going alpha cycle), the perception of their temporal order apparently changes from “simultaneous” to “sequential” (e.g., Varela, Toro, John, & Schwartz, 1981). That said, only further investigation of the information processing of sequentially presented tactile stimuli by means of psychophysiological and psychophysical measures will be able to answer the question of whether or not such a mechanism can be extended to explain the “window of consciousness” in the tactile modality (see Vibell, Klinge, Zampini, Spence, & Nobre, 2007).

We believe that in order to highlight the factors that modulate the temporal aspects of our conscious representation of tactile stimuli (such as their spatial attributes) one must also consider conditions of bimodal stimulus presentation. With regard to this point, temporal processing has also been studied between different sensory modalities by means of both TOJ and simultaneity judgment (SJ) tasks (e.g., visual and tactile, or visual and auditory; e.g., Hirsh & Sherrick, 1961; Rutschmann & Link, 1964; Spence, Baddeley, Zampini, James, & Shore, 2003; Spence et al., 2001b; Vibell et al., 2007; see also Craig, 2005; Craig & Busey, 2003; and see Spence & Parise, 2010, for a review). The importance of the results of these studies is related to the fact that they provide information regarding the temporal window within which stimuli presented in different sensory modalities (and that are initially analyzed in different areas of the brain) will likely be consciously perceived as being simultaneous (and thus perhaps providing the basis for being perceived as belonging to a single multisensory object; cf. Driver & Spence, 2000; Spence et al., 2003; Stein & Meredith, 1993; see also Noesselt, Bergmann, Heinze, Münte, & Spence, 2012). Indeed, given that information from different sensory modalities arrives at the relevant primary analysis structures in the brain at different times (e.g., it has been estimated that it takes 1 ms for auditory stimuli to be transduced at the cochlea, but 30–40 ms for visual stimuli at the retina and something between these two values for tactile stimuli; e.g., Artieda & Pastor, 1996; Poppel, 1997; Pöppel, Schill, & von

Steinbüchel, 1990; Spence & Squire, 2003; Sugita & Suzuki, 2003; see also Schroeder & Foxe, 2002, 2004), a mechanism that binds together the stimuli falling within a given spatiotemporal window would presumably be of importance (together with other attributes such as shared semantic meaning or common fate; see Chapter 3) for the unitary perception of the multisensory objects and events around us (see Fiebelkorn, Foxe, & Molholm, 2012; for a discussion on the neural mechanisms underlying multisensory features binding).

However, while binding appears to be necessary for an observer to attribute different sensory stimuli to the same object (e.g., Bedford, 2001, 2004), and therefore organize a coherent response to it, whether or not consciousness of a “multisensory object” is possible is still a matter of some theoretical debate (e.g., Fraise, 1964; Guinzberg, 1928; Pieron, 1952; see also Spence & Parise, 2010; see also Spence & Bayne, *in press*). The relevant question here is whether or not, for example, we can be aware of the red color of a fire and at the same time of the warm sensation that it elicits on our skin. The issue is therefore one of whether consciousness should be considered as multisensory or unisensory? Previously, researchers have been skeptical about the former possibility, suggesting that the impression of simultaneity can occur for stimuli presented within a given sensory modality, but not for stimuli presented to different sensory modalities (e.g., Fraise, 1964; Guinzberg, 1928; Pieron, 1952). That is, according to these researchers we can be conscious of several sensory qualities of a stimulus at any one time only if they all occur within the same sensory modality, but not of qualities perceived by different sensory modalities. By contrast, other researchers have argued that people can actually judge the apparent simultaneity of stimuli across the senses reasonably well (e.g., Hirsh & Sherrick, 1961; see Spence et al., 2001a; Spence & Bayne, *in press*, for reviews).

For example, the participants in a classic study by Hirsh and Sherrick (1961) had to determine which of two consecutively presented stimuli, one from each of two sensory modalities (i.e., vision-audition, vision-touch, or touch-audition), or both from the same sensory modality (i.e., vision-vision, touch-touch, or audition-audition), had been presented first. These researchers reported that the interval required for the expert psychophysical observers in their study to correctly judge the temporal order of the stimuli was approximately 20 ms, regardless of the pair of sensory modalities under investigation. These data have been taken to suggest that the same mechanisms postulated to resynchronize asynchronous sensory signals occurring within a particular sensory modality might also, in fact, be used to resynchronize stimuli presented in different sensory modalities (e.g., Grossberg & Grunewald, 1997). That is, the same central and perhaps multisensory system might be responsible for the temporal qualities of consciousness for stimuli presented in all of the senses (or at least for the modalities of audition, vision, and touch studied to date; though see Kobayakawa and Gotow, 2011).

Fujisaki and Nishida (2010) recently provided evidence to support the view that a common temporal limit might affect the binding of stimuli presented to different sensory modalities. In particular, the participants in their study were instructed to judge the combination of attribute values of stimuli (e.g., combinations of color and pitch) that were presented at the same time (the binding task), or to judge synchrony between two sequences of stimuli (the synchrony task). The stimuli used were combinations of visual (color), auditory (pitch), and tactile (body position) attributes. The results revealed that the upper limits of crossmodal binding were lower than those of unimodal binding, but similar for any combination of visual, auditory and tactile attributes (see also Fujisaki, Kitazawa, & Nishida, 2012).

Note, however, that Spence et al. (2003) have demonstrated that people’s sensitivity to temporal order when reporting which of two sensory modalities (vision and touch) had been presented first was influenced by the body posture that the participant adopted (e.g., hands uncrossed or hands

crossed; see also Axelrod et al., 1968). Moreover, participants require a shorter temporal interval between stimuli in the two modalities in order to determine their correct order of presentation when pairs of auditory and visual stimuli were presented from different positions, rather than from the same position (e.g., Zampini, Guest, & Spence, 2003). Such results suggest that the *spatial*, as well as temporal, properties of the stimuli presented, together with the particular discrimination task that participants have been instructed to perform, constitute important determinants of our conscious perception of the temporal order of the events taking place in the world around us (see also Kitagawa et al., 2005; Zampini et al., 2005).

4.3 Change blindness

In order to reduce processing resources to a minimum, our neurocognitive systems are structured with the express purpose of selecting and processing only relatively little information from the external environment. Some information is selected and enters our awareness, some is not and fades away somewhere in our information processing systems. Are there any rules about what is selected and what is not? From an ecological point of view, one of the most relevant sorts of information in the environment is the occurrence of change. In fact, a change in the status of our environment likely signals the presence of something that is potentially relevant, like the appearance of a prey or food, or something potentially dangerous, such as a predator or a possible hazard, and this likely needs a more or less rapid response. Research over the last half century or so has revealed that an observer's awareness of visual stimuli can be disrupted by the concurrent presentation of some form of disruption (or distraction). In particular, people appear to be surprisingly inept at consciously detecting changes introduced between one visual scene and the next, both in laboratory settings, and under more ecologically valid testing conditions (e.g., DiVita, Obermayer, Nugent, & Linville, 2004; French, 1953; Hochberg, 1968; Rensink, 2002; Simons, 2010; Simons & Rensink, 2005; Smith, Lamont, & Henderson, 2012; Velichkovsky, Dornhoefer, Kopf, Helmert, & Joos, 2002; see Chabris & Simons, 2011, for a recent review). Many different stimuli/events have been shown to elicit visual change blindness when presented between two to-be-compared visual scenes: These include a blank (or black) screen (e.g., Rensink, O'Regan, & Clark, 1997), eye blinks (e.g., O'Regan et al., 2000; Velichkovsky et al., 2002), saccades (e.g., Grimes, 1996), movie cuts (e.g., Levin & Simons, 1997), secondary tasks (e.g., Saiki & Holcombe, 2012), and multiple discrete masking elements known as "mudsplashes" (e.g., O'Regan et al., 1999; see also Simons, Franconeri, & Reimer, 2000; Turatto, Bettella, Umiltà, & Bridgeman, 2003).

With regard to the tactile modality, it is only within the last decade or so that the phenomenon of change blindness has begun to attract the attention of researchers. This lack of research interest is surprising considering that every day people are pick-pocked in our big cities (a crime that result in up to 1700 victims every day in Britain alone and that has increased by 17% in the last couple of years; <<http://www.dailymail.co.uk/news/article-2175867/London-Olympics-2012-As-1-700-fall-victim-pickpockets-day-Eastern-European-gangs-it.html>> downloaded on October 22, 2012). A wallet or purse being gently slipped from your pocket in a crowded underground and going totally unnoticed by you the owner, might indeed be considered as a clear example of change blindness in the tactile domain.

In one of the first studies to have been published in this area, Gallace, Tan, and Spence (2006b) demonstrated that their participants frequently failed to detect the presence of positional and identity changes between simple consecutively presented vibrotactile patterns (composed of two or three discrete vibrotactile elements) presented over their body surface (see also Gallace, Tan, & Spence, 2005). The lack of awareness of change occurred when the two consecutively presented

tactile patterns are separated by a temporal interval of as little as 110 ms, or when a tactile mask was presented between them. However, this never occurs when there was no temporal gap between the displays. Given the apparent similarity between tactile and visual change blindness, this phenomenon in touch might be named “change numbsense” (see section 4.6 on the topics of neglect, extinction, and numbsense). However, further investigation is certainly warranted in order to verify the extent to which change blindness in vision and touch are actually based on similar cognitive mechanisms (see Gallace, Tan, & Spence, 2006b, 2007c; and Auvray, Gallace, Tan, & Spence, 2007a, for further discussion of this point).

Tactile change blindness has also been demonstrated when localized tactile distractors are superimposed on the display at the moment of change (Gallace et al., 2007c), in a similar fashion to that reported previously using the mudsplash paradigm within visual displays (O'Regan et al., 1999). That is, if an observer has to try and detect the presence versus absence of a change between two consecutively presented tactile patterns presented over their body surface, the stimulation of an additional body position at the moment of change will result in a decrease in change detection performance (and, in this case, even when no temporal gap separates the two patterns). Furthermore, it turns out that not only tactile but also visual distractors may elicit change blindness for displays composed of as few as one to three tactile stimuli (Auvray et al., 2007a; Gallace et al., 2007c).⁴

It has been proposed that change blindness in touch (as well as in vision) might be related to the failure of a stimulus to reach awareness within a spatial representation (likely multisensory/amodal) where that change is neurally represented (see Gallace et al., 2006a, 2007c). This might be determined by the competition between concurrently stimulated positions (see Cole, Kentridge, Gellatly, & Heywood, 2003; Desimone & Duncan, 1995) within such a representation. This, together with the absence of the transients that normally generate an orientation response toward the location of change (cf. Hollingworth, Simons, & Franconeri, 2010), and/or increase the neural activation of a given representation in the brain (cf. Desimone & Duncan, 1995)⁴ results in the failure to detect the change. Following on from these arguments, one might, once again, conclude that the access to consciousness of tactile information (in this case of the presence of changes between consecutively presented displays) might be strictly related to the processing of *spatial* information in the brain.

Possible neuroscientific support for this view comes from the results of a neuroimaging study reported by Downar, Crawley, Mikulis, and Davis (2000). Using event-related fMRI, these authors demonstrated that a right-hemisphere network including the temporoparietal junction (TPJ) was activated whenever observers had to detect visual, auditory, or *tactile* changes (see also Beck, Rees, Frith, & Lavie, 2001). It is worth noting here that the right TPJ is an area that has often been reported to be involved in the processing of spatial information (e.g., de Haan, Karnath, & Driver, 2012; Karnath, Ferber, & Himmelbach, 2001; Vallar, 2001).

The analysis of the phenomenon of tactile change blindness (or numbsense) highlights a number of similarities and differences with the equivalent phenomenon in vision. In particular, the failure to detect changes to tactile stimuli presented over the body surface has been observed

⁴ It is important to note that not only visual transients presented on the body itself but also visual stimuli presented at some distance (i.e., on a wall situated 2 m from a participant's body) can elicit tactile change blindness (Gallace et al., 2006a). This result suggests that the representation in which the stimuli compete for access to consciousness is not necessarily a somatotopic one, but may instead constitute a more allocentric or environmental spatial representation.

when no more than two to three factors were activated at any given time (Gallace et al., 2006a, 2007b). These results clearly contrast with the findings reported in previous studies of visual change blindness, where a failure to detect change was typically only reported for complex and detailed visual scenes containing at least five items (e.g., Rensink, 2002). Note also that only “one” distractor used as a mudsplash and presented elsewhere on the body surface is needed in order to elicit tactile change blindness under the appropriate conditions. By contrast, when it comes to visual perception, typically many distractors must be presented in order to elicit the phenomenon (e.g., see O’Regan et al., 2002). Furthermore, while change numbness can be elicited using visual distractors, tactile distractors have been shown to be ineffective in eliciting change blindness with visual displays composed of no more than three or four stimuli (Auvray et al., 2007a).

Different interpretations can be put forward in order to account for these apparent discrepancies between the awareness of change in the visual and tactile modalities. Specifically, the difference between the two sensory modalities in the number of stimuli and distractors that can elicit change blindness can be explained by: (1) The different limit of “subitizing” for vision and touch (though see the previous section for a critical view on this point); (2) The fact that the stimuli in the experiments that have demonstrated the presence of change numbness were presented on the body surface rather than to the fingertips. Remember that the limit in the number of stimuli that elicit change blindness in vision was typically obtained by presenting the stimuli in a limited spatial area, and generally close to the fovea (or else the image was presented for a sufficient time to allow the participants to bring the details of the visual scene onto their fovea). Different results might well be expected with stimulation on parts of the body that have a larger neural representation in the brain, such as, for example, the fingertips (cf. Baron & Pelli, 2006); (3) The storage capacity of sensory memory for visual and tactile stimuli presented across the body surface might be fundamentally different. Indeed, it should be noted that the representation of a visual scene appears to be limited to the number of items that can be held in visual short-term memory (STM) at any one time (e.g., Miller, 1956; Pashler, 1988; Pylyshyn & Storm, 1988; Rensink, 2002; Shipstead, Harrison, & Engle, 2012; see also Elmore, Ma, Magnotti, Leising, Passaro, Katz, & Wright, 2011); (4) While it is possible to limit the amount of visual information that participants have access to in a visual change blindness experiment (i.e., by presenting visual stimuli on a monitor in an otherwise completely dark testing room), there might be additional tactile information available in tactile experiments that cannot easily be controlled for by the experimenter (such as, for example, the feeling of the participants’ clothes on their skin, points of contact, or reference, of the participants’ body on the chair, response keys, etc.; though see Graziano, Alisharan, Hu, & Gross, 2002; Holmes & Spence, 2006). These data would suggest that our awareness of tactile information might be affected by irrelevant information presented concurrently and perhaps processed implicitly by our brain.

Finally, the fact that visual distractors can elicit tactile change numbness while the presentation of tactile distractors apparently cannot elicit visual change blindness might also be taken to suggest that visual stimuli are simply more effective in terms of increasing neural activity across a multisensory/amodal representation required for the access to consciousness of spatially organized information (cf. Desimone & Duncan, 1995; see Auvray et al., 2007a). Alternatively, however, it could also be claimed that visual stimuli might be more effective than tactile stimuli in exogenously attracting spatial attention. Note, however, that these two interpretations are not necessarily mutually exclusive (though see Kennett, Spence, & Driver, 2002; Spence, Nicholls, Gillespie, & Driver, 1998; for evidence suggesting robustly symmetrical links in attentional capture between touch and vision; see also Spence, 2010; Spence et al., 2004). Indeed, it has been suggested that the same neurons involved in maintaining spatial representations may also be involved in attention

(e.g., Andersen, 1995; Cohen, Farah, Romero, & Servan-Schreiber, 1994; Gottlieb, Kusunoki, & Goldberg, 1998; see also Pouget & Sejnowski, 2001).

4.4 Inattentional blindness

Cognitive scientists have reported that people may lack an awareness of even very salient visual stimuli/events when their attention is focused on a different stimulus, event, or task. This phenomenon has been named “inattentional blindness” (e.g., Chica, Lasaponara, Chanes, Valero-Cabré, Doricchi, Lupiáñez, & Bartolomeo, 2011; Cohen, Alvarez, & Nakayama, 2011; Thakral, 2011; see Mack & Rock, 1998, for an early review; though see Braun, 2001, for a critical discussion regarding whether or not the phenomenon should actually be related to attention in the first place). As compared to the visual modality, no serious attempt has yet been made to study the phenomenon of “inattentional blindness” in the tactile (or auditory) modality (though see Mack & Rock, 1998). Indeed, the few studies that have addressed the role of attention in the conscious perception of tactile events only used the *sequential* presentation of individual stimuli, rather than patterns (and their results have been interpreted within the framework of the “attentional blink” phenomenon; e.g., Dale, & Arnell, 2013; Dell’Acqua, Jolicoeur, Sessa, & Turatto, 2006; Hillstrom, Shapiro, & Spence, 2002; Lagroix, Spalek, Wyble, Jannati, & Di Lollo, 2012; Soto-Faraco, Spence, Fairbank, Kingstone, Hillstrom, & Shapiro, 2002).

In particular, when participants have to try and detect two targets embedded within a continuous stream of visual stimuli (a paradigm known as “rapid serial visual presentation,” RSVP), they frequently fail to report the second target in the sequence (e.g. Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992). Broadbent and Broadbent proposed that this phenomenon (termed the “attentional blink”—AB; Raymond et al., 1992) occurred because the processing of the first target interfered with the identification of the second target. Note here that an AB has also been reported for sequences of tactile stimuli (composed of pairs of targets and their associated masking stimuli; e.g., Hillstrom et al., 2002), and even for sequences composed of multisensory stimuli (e.g., Dell’Acqua, Jolicoeur, Sessa, & Turatto, 2006; Ptito, Arnell, Jolicoeur, & Macleod, 2008; Soto-Faraco et al., 2002), thus suggesting a common, perhaps amodal/multisensory, mechanism underlying it. Note, though, that Hillstrom and her colleagues only ever observed a tactile AB when their participants had to perform a *spatial* task, once again suggesting the importance of spatial processing in modulating people’s awareness of tactile stimuli.

Although the precise neural mechanisms underlying the AB are still rather unclear, even if an important role would seem to be related to the activity of the prefrontal cortex (see Dell’Acqua, Sessa, Jolicoeur, & Robitaille, 2006; Marois, Yi, & Chun, 2004; Shapiro et al., 2007; Thakral, 2011), its presence clearly suggests that tactile consciousness of a specific event may be affected (up to the point where stimuli go completely undetected) by previously presented events, even when presented in a different sensory modality (e.g., Soto-Faraco et al., 2002). This might be related to the competition between consecutively presented stimuli in terms of their ability to gain control of action (e.g., Duncan, Ward, & Shapiro, 1994; Shapiro & Raymond, 1994). That is, certain stimuli, perhaps those occurring in more salient regions of space, or rather carrying more relevant informational content (i.e., for a particular task), might be favored in the competition to gain access to consciousness and the control of actions, under conditions in which multiple responses are required.

As compared to the relatively well-studied effects of attention in the temporal processing of sequentially presented tactile stimuli, the role of attention in the conscious detection of changes between consecutively presented *tactile* patterns (i.e., under conditions similar to those that are

known to give rise to the phenomenon of inattentional blindness in vision) still remains largely unexplored (though see Mack & Rock, 1998, for a few preliminary examples of attentional blindness in a multisensory setting). Given that many researchers working in the area of visual perception have claimed that attention is essential for our awareness of change, and in general for our conscious perception of the world around us, this point should be certainly considered in further research (e.g., Rensink et al., 1997).

The latter claim has given rise to what has been called “the paradox of perceptual attention” that can be summarized as follows: To consciously perceive details in the environment, you must direct your attention to them. But how can you direct your attention to an unperceived feature of a scene (see Noë & O’Regan, 2000, for a discussion of this point)? One should also consider the fact that the specific role that may be attributed to attention in the conscious perception of tactile stimuli depends to a large extent on the definition of attention that one chooses to adopt (e.g., if attention is thought of as a “cause” or as an “effect” of selective information processing in the cognitive system; see Fernandez-Duque & Johnson, 2002; Johnston & Dark, 1986). Although the question of the role of attention in conscious perception is undoubtedly more complex than has been highlighted here, we believe that no complete account of people’s awareness of tactile change can be made without an empirical investigation of this important topic (cf. Koch & Tsuchiya, 2007).

Many questions still remain unanswered regarding people’s awareness of change in the tactile modality. In particular, an important issue that deserves further research regards the fate of information that has not been explicitly detected following a change. Studies of visual change blindness have demonstrated that stimuli that go unreported in change detection tasks can nevertheless still implicitly affect a participant’s subsequent task performance (e.g., Fernandez-Duque, Grossi, Thornton, & Neville, 2003; Fernandez-Duque & Thornton, 2000; Hollingworth et al., 2001; Laloyaux & Cleeremans, 2005; Kimura, Katayama, & Ohira, 2008; Thornton & Fernandez-Duque, 2000; though see Mitroff, Simons, & Franconeri, 2002). Therefore it seems plausible to think that, just as for the case of vision, representations of tactile stimuli that do not have access to consciousness (for the purpose of explicit report), may still be accessed using alternative procedures (i.e., more indirect or implicit; e.g., Fernandez-Duque & Thornton, 2000; Hollingworth et al., 2001; see also Cohen, 2002).

The neural mechanisms underlying the explicit and ultimately implicit detection of tactile change will, in the future need to be investigated by means of neuroimaging techniques (e.g., Fernandez-Duque et al., 2003; Kimura et al., 2008). On the basis of the observations reported in this section, we would expect implicit change detection to activate the primary somatosensory areas, while explicit change detection would also require the activation of higher-order association areas, such as those involved in the processing of spatial information (e.g., Beck et al., 2001; Downar et al., 2000). The results of these studies would therefore be expected to provide a more complete view of the neural substrates responsible for the awareness of tactile information in humans.

4.5 Memory and consciousness: The “tactile present”

Some form of very short-term memory seems to be essential for consciousness, but this memory may well be very transient, lasting for only a fraction of a second (cf. Wolfe, 1999). Edelman (1989) has used the phrase, “the remembered present,” to make this point. The existence of very short-term forms of storage has been well-established experimentally in the case of visual perception (e.g., Coltheart, 1980; Gegenfurtner & Sperling, 1993). Early on, Sperling (1960) demonstrated

that participants who were requested to remember all of the letters or numbers in visual matrices presented for 500 ms were able to report an average of about four or five items. However, by using a partial report paradigm (i.e., by presenting an acoustic probe that indicated which row of the matrix of characters had to be reported), the storage capacity for the visual array was estimated at 12–18 items. Such a result has been taken to demonstrate the existence of a specific representation (i.e., "iconic memory"; see Neisser, 1967) of high capacity but which is subject to very rapid decay (see Coltheart, 1980, for a review; see also Chapter 5, for a more comprehensive review of studies that have investigated tactile memory).

Empirical research has also established the presence of an auditory short-term form of storage system named "echoic memory" (e.g., Cowan, 1984). Although both psychophysical and neurophysiological aspects of these forms of memory have been extensively investigated in the visual and auditory modalities (e.g., Coltheart, 1980; Lu, Williamson, & Kaufman, 1992), this phenomenon has been left virtually unexplored in the tactile modality. The few studies that have, to date, attempted to explore short-lasting memory in tactile perception primarily concentrated on what has been called short-term memory (STM). The results of these studies, in which stimuli have only ever been presented to the fingertips, have led to the suggestion that the immediate memory span for tactile stimuli following brief (i.e., 100 ms) presentation varies from 3.5–7.5 stimuli and that tactile STM performance declines to an asymptotic level (i.e., the lowest level of performance in a recollection task) within 45 seconds of stimulus presentation (e.g., Bliss, Hewitt, Crane, Mansfield, & Townsend, 1966; Gilson & Baddeley, 1969; Miller, 1956; Rabinowitz, Houtsma, Durlach, & Delhorne, 1987; cf. Hillstrom et al., 2002; see also Chapter 5).

However, to the best of our knowledge, to date, only one study has attempted to investigate even shorter-term forms of tactile memory (i.e., comparable to the iconic and echoic storage systems in vision and audition, respectively). Specifically, Bliss et al. (1966) investigated the ability of participants to report the locations of multiple tactile stimuli presented simultaneously. They delivered up to 12 stimuli to the 24 inter-joint segments of the participants' fingers (the thumbs were excluded). Using an alphabetic labeling system, the participants in Bliss et al.'s study were required to report the digit segments stimulated after each presentation. These researchers reported that when the participants had to report the stimuli presented to all eight fingers (this is known as "whole report") the maximum number of stimuli that participants could correctly report called about 3.6 (out of a maximum of 12 possible correct). However, when using a partial report procedure (by presenting post-stimulus cuing of individual digits) the participants could successfully report only one more location (i.e., 4.6 correct) as compared to the whole report procedure (i.e., a very modest improvement in performance relative to that seen in vision).

Bliss et al.'s (1966) data might therefore be taken to suggest the presence of a tactile sensory storage system of brief duration (estimated at approximately 0.8 sec by Bliss and his colleagues) and slightly greater storage capacity (at least as compared to longer lasting forms of storage), analogous to the iconic and echoic systems that have been highlighted in vision and audition (cf. Rabinowitz et al., 1987). However, their results also suggest that any tactile STM seems to have considerably less capacity than the analogue form of visual memory. Bliss et al. claimed that "spatial interactions," due to the reciprocal masking of simultaneously presented tactile stimuli might, in part, help to explain their data. The differences that arise when STM for visual and tactile stimuli are compared, will obviously need to be addressed in future research. Moreover, before drawing any firm conclusions regarding the difference in STM for visual and tactile stimuli, the role that practice may play in improving tactile memory must also be considered as an object of future investigation (e.g., Hodzic et al., 2004).

In conclusion, our consciousness of tactile stimuli, as well as our consciousness of visual and auditory stimuli, might be sustained by STM systems with a large capacity but very rapid decay. However, many different questions regarding this important topic still remain unanswered. In particular, future research should address the following questions: Is the STM capacity for tactile stimuli presented on the fingertips different to that for stimuli presented across the rest of the body surface? What, if any, is the relation between the duration of STM and its capacity limit? (Note that the preliminary results obtained by Gallace et al., 2008b, in which tactile stimuli were presented across the body surface, and a probe for recall was presented after a variable delay in one of the stimulated locations, suggested that the temporal limitations of tactile STM representations might be a function of the number of stimuli presented in the display.)

On the basis of which spatial frame of reference are these short-term tactile representations stored (i.e., somatotopic or allocentric)? What are the neurological substrates for this form of memory (see Bonda, Petrides, & Evans, 1996, for the report of the involvement of a parieto-insular neural pathway, including the posteroventral insula and the perirhineal cortex in the recall of tactile patterns; see also Kaas, van Mier, Visser, & Goebel, 2013, for the involvement of the secondary somatosensory cortex, the dorsolateral prefrontal cortex and the superior parietal lobule, in the representation of haptically explored textures in working memory)? Is the STM for tactile, as well as for visual and auditory stimuli, modality-specific or are STM representations amodal (i.e., shared between different sensory modalities; see Spitzer & Blankenburg, 2012)? And if STM representations are modality-specific, what is the nature of the interactions between different STM representations (i.e., visual and tactile; cf. Gallace et al., 2008b)? It is only after proper answers have been provided to these important questions that a clearer understanding of the temporal properties of consciousness for tactile stimuli will be arrived at.

4.6 Consciousness of tactile stimuli: The “where” problem (body, space, or both)

Although common sense might appear suggest that the conscious localization of tactile stimuli depends only on the region of the body that has been stimulated, the available scientific evidence now suggests that this may not be the case. Surprisingly it has been found that participants may refer tactile sensations to locations in space different from those occupied by the part of the body that has been stimulated (e.g., Pavani, Spence, & Driver, 2000; Tastevin, 1937; Welch, 1972; cf. Hay, Pick, & Ikeda, 1965; Nielsen, 1963; Olivé & Berthoz, 2012; Rossetti, Desmurget, & Prablanc, 1995; Shimojo, 1987). For example, Pavani et al. asked the participants in their study to report the perceived location of vibrotactile stimuli while their upper limbs were placed out of view below an occluding screen on which a pair of stuffed rubber gloves (i.e., artificial hands) was placed (see Figure 4.1). Pavani and his colleagues found that their participants often reported feeling the stimuli in the location where they saw the rubber hands, or that they even felt the rubber hands as being their real hands (see also Botvinick & Cohen, 1998; Ehrsson, Spence, & Passingham, 2004; Haans, Kaiser, Bouwhuis, & IJsselstein, 2012; Moseley, Olthof, Venema, Don, Wijers, Gallace, & Spence, 2008a; Olivé & Berthoz, 2012; Tastevin, 1937; Tsakiris & Haggard, 2005; see also Chapter 8).

More importantly for present purposes, Pavani et al. (2000) reported that visual distractors presented on the rubber hands themselves influenced participants' discrimination judgments regarding the location of the tactile stimuli as a function of the compatibility between the position of the rubber hands and the posture of their participants' own hands. Specifically, the effect of visual distractors was larger when the rubber hands were aligned with the participants' own hands (i.e.,

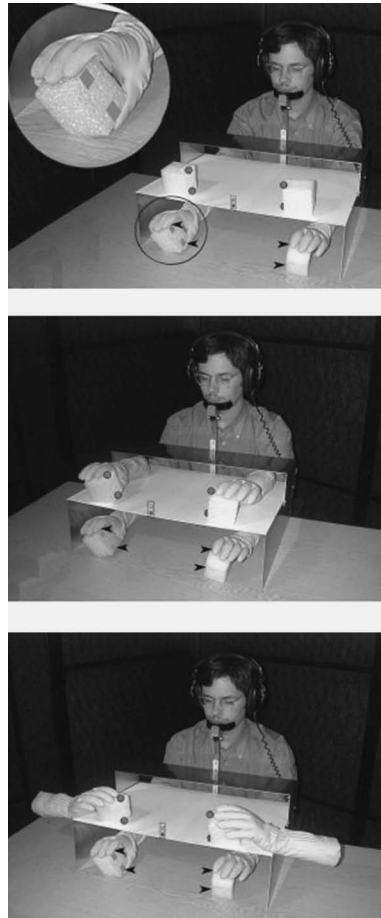


Fig. 4.1 Set-up adopted in Pavani et al.'s (2000) study of the rubber hand illusion. Data from *Psychological Science*, **11** (5), pp. 353–359, F. Pavani, C. Spence, and J. Driver, Visual capture of touch: Out-of-the-body experiences with rubber gloves, 2000.

mimicking the position that would have been assumed by the real hands raised on the table). On the basis of their results, the authors suggested that the brain might weight visual information about posture more strongly (as compared to proprioceptive information), especially when the visible location of a limb falls into the range of possible proprioceptively indicated postures. Finally, the fact that Pavani et al.'s results were obtained not only by using qualitative questionnaire measures (e.g., Botvinick & Cohen, 1998), but also by using indirect psychophysical measures (congruency effects in a speeded crossmodal distractor congruency task; see Spence et al., 2008, for a review), allowed the authors to suggest that the visual influence on tactile localization appears to be cognitively impenetrable, reflecting perceptual processing rather than simply a participant's belief (e.g., Radeau, 1994; see also Durgin, Evans, Dunphy, Klostermann, & Simmons, 2007; Moseley et al., 2008a). That is, people's psychophysiological parameters alone are sufficient to determine whether or not the illusion is induced regardless of a participant's insight about it.

The mirror reflection of a limb (typically the hand and arm) has been used to induce visual-proprioceptive conflicts in both neurologically normal participants and in brain-damaged patients. For example, Ro, Wallace, Hagedorn, Farnè, and Pienkos (2004) asked the participants

in their study to look at a mirror reflection of their right hand being brushed by the experimenter. Note that under such conditions the visual information available to the participants (i.e., the mirror reflection of their right hand) suggested visually to them that their left hand was being touched, while the tactile information suggested that only the right hand was being touched (see also Bremner, Hill, Pratt, & Spence, 2012; Holmes, Crozier, & Spence, 2004; Holmes, Snijders, & Spence, 2006; Holmes & Spence, 2005; Moseley et al., 2008a; Snijders, Holmes, & Spence, 2007; cf. Gallace & Spence, 2005; Soto-Faraco, Ronald, & Spence, 2004). After 2.5 minutes of adaptation using this procedure, many of the participants reported feeling tactile sensations in their left hand, although they knew that this limb had actually not been stimulated. More importantly, Ro et al. measured the sensitivity of their participants' left hand (which had not been touched in the study) both before and after the adaptation procedure. Surprisingly, they observed a significant change in tactile sensitivity in the "untouched" hand. In particular, explicit detection of tactile stimuli presented at near-threshold levels on the untouched hand was increased following exposure to the mirror (i.e., after vision of their "virtual" left hand—mirror image of their right hand—being touched).

Interestingly, Ro et al. (2004) also demonstrated that the visual enhancement of tactile perception elicited by the presence of a mirror placed between the participant's hands in their study could be eliminated by applying transcranial magnetic stimulation (TMS) to the participants' right posterior parietal cortex (but not by applying TMS to their frontal cortex), suggesting this as a possible neural substrate for the visual capture of tactile sensation (cf. Ehrsson et al., 2004). Relevant here is the proposal that the posterior parietal cortex combines information from different sensory modalities in order to create a common representation of extrapersonal space (e.g., Andersen, Snyder, Bradley, & Xing, 1997; Cohen, 2009; Critchley, 1966; Graziano, 2001; Pouget & Driver, 2000; Spence & Driver, 2004; see also Pouget & Sejnowski, 2001, for a computational model of spatial representation in humans; cf. Magosso, Cuppini, & Ursino, 2012; Velik, 2012). It has also been suggested that the neurological substrate of such a representation might be instantiated in neurons with spatially congruent receptive fields for stimuli presented in different sensory modalities (e.g., Andersen et al., 1997; Pouget & Driver, 2000).

Following on from these arguments, it would appear possible that the awareness of tactile information might also require (and be influenced by) stages of information processing mediated by higher-order, likely multisensory, areas of the brain, where spatial information is represented (though see Ghazanfar & Schroeder, 2006). Specifically, signals from multisensory brain areas, such as the posterior parietal cortex, might project (down) to the somatosensory areas, creating a network that is responsible for our awareness of tactile information (e.g., Sarri et al., 2006; Taylor-Clarke, Kennett, & Haggard, 2002; though see Fiorio & Haggard, 2005). The functioning of such brain circuits might also help to explain the frequently reported enhancement of tactile perception by means of visual stimulation, such as when watching one's own body part (e.g., Cardini, Longo, Driver & Haggard, 2012; Fiorio & Haggard, 2005; Kennett, Taylor-Clarke, & Haggard, 2001; Longo, Musil, & Haggard, 2012; Press, Taylor-Clarke, Kennett, & Haggard, 2004; Ro et al., 2004; Schaefer, Heinze, & Rotte, 2005; Taylor-Clarke, Kennett, & Haggard, 2004).

Alternatively, however, one should also consider the possibility that information from different sensory modalities (e.g., vision, audition) can enhance the awareness of a signal presented in another sensory modality (e.g., touch) within the very unisensory area that is involved in the initial processing of such a signal in the first place (e.g., the somatosensory cortex). That is, the substrate for multisensory integration is already present at the primary cortical levels of information processing (e.g., Cappe & Barone, 2005; Rockland & Ojima, 2003; see also Ghazanfar & Schroeder, 2006, for a review). Whatever the resolution of the debate regarding the cortical

mechanism(s) responsible for the enhancement of tactile processing by means of visual information turns out to be, these observations would also appear to suggest that one’s awareness of tactile (as well as of visual and auditory) events should always be considered within an interpretational framework that is “multisensory.” The latter observation does not contrast with the earlier claim that tactile consciousness may be unisensory in nature (i.e., in terms of its phenomenology; see section 4.1).

As previously mentioned (see section 4.2.2 and Chapter 3, section 3.3.2) the performance of neurologically normal participants asked to discriminate the order in which two consecutively presented tactile stimuli are delivered on the skin (see section 4.5) is modulated by the position in which their hands are placed (e.g., Cadieux, Barnett-Cowan, & Shore, 2010; Shore, Spry, & Spence, 2002; Yamamoto & Kitazawa, 2001; Zampini et al., 2005; see Gallace, Torta, Moseley, & Iannetti, 2011, for a similar effect using both tactile and noxious stimuli). Once again, it is important to note here that not only does the real position of a participant’s hands affect this putatively unimodal form of tactile processing, but also their visually perceived position (cf. Soto-Faraco et al., 2004). Indeed, Gallace and Spence (2005) have reported that when the visually perceived position of participants’ hands is varied (by means of the mirror reflection of one hand), keeping the real positions between the hands constant, similar effects to those observed by varying the real position of the hands can be obtained (see also Moseley, Gallace, Di Pietro, & Iannetti, 2013, for analogous effects obtained by shifting the visually perceived position of the hands by means of prism lenses). In particular, the minimum temporal separation between the tactile stimuli needed to evaluate which of the hands was stimulated first (i.e., the just noticeable difference; JND), increased with a decrease in the visually perceived distance between the hands (i.e., in manner similar to that reported by actually varying the physical distances between the hands; e.g., Shore et al., 2005).

Taken together, the results reported in this section suggest that: (1) The perception of the temporal ordering of stimuli presented on the skin is determined only after the stimuli have initially been localized in space (see Kitazawa, 2002; Shore, Spry, & Spence, 2002; Wada, Yamamoto, & Kitazawa, 2004; Wieland, 1960; though see also Gallace, Soto-Faraco, Dalton, Kreukniet, & Spence, 2008); and (2) The conscious perception of touch is not necessarily determined simply by the location of the stimulated receptors on the skin, but may instead be referred flexibly to different locations in external space (e.g., Gallace & Spence, 2005; Kitazawa, 2002; Yamamoto & Kitazawa, 2001; see also Haggard, Kitadono, & Taylor-Clarke, 2006).

4.6.1 Phantom sensations in amputated limbs

An important body of evidence concerning the role played by *spatial information* and the neural substrates of the tactile awareness of events comes from the study of patients suffering the amputation of one or more body parts. Indeed, tactile “phantom” sensations may be evoked in the amputated portion of the limb by means of the appropriate stimulation (see Björkman, Weibull, Olsrud, Ehrsson, Rosén, & Björkman-Burtscher, 2012; Giummarra & Moseley, 2011; James, 1887; Jensen, Krebs, Nielsen, & Rasmussen, 1983, 1984; Ramachandran & Hirstein, 1998; Weinstein, 1969; see also the novel *Moby Dick* by H. Melville; de Lafuente, & Marques, 2003). Specifically, the tactile stimulation of the stump of an amputated limb, or even of regions distant from the amputation may elicit tactile, caloric, and/or pain sensations in the amputated phantom limb (e.g., Aglioti, Bonazzi, & Cortese, 1994; Aglioti, Cortese, & Franchini, 1994; Ramachandran & Hirstein, 1998; Weinstein, 1969; see Ramachandran, 1993, for a review). That is, the sensations are referred to the location where the amputated limb was before it was surgically removed.

Interestingly, a point-to-point correspondence between the actual position of the stimulus presented and the position of perceived stimulation on the phantom limb has been demonstrated in individual amputees. These correspondences are so accurate as to make it possible in certain cases to construct complete maps of the phantom limbs (e.g., the hand) across the location of the body where the stimuli are presented (e.g., one side of the face; e.g., Ramachandran, Rogers-Ramachandran, & Stewart, 1992; Ramachandran, Stewart, & Rogers-Ramachandran, 1992; see also Henry, Chiodo, & Yang, 2011). On the basis of such evidence, it has been suggested that the phantom sensations frequently reported by amputees after stimulation of a different area/part of the body may reflect the consequence of the reorganization of the somatosensory cortex that follows the loss of afference from the amputated limb (e.g., Ramachandran et al., 1992a; see also Berlucchi & Aglioti, 1997). For example, phantom hand sensations following stimulation of the face might be caused by the appropriation of the initial representation of the amputated hand by the afferent input normally directed to the representation of the face (e.g., Pons, Garraghty, Ommaya, Kaas, Taub, & Mishkin, 1991; see also Clarke et al., 1996). Indeed, those regions of the somatosensory cortex that are believed to sustain the representation of the hands and face lie adjacent to one another (e.g., Nakamura, Yamada, Goto, Kato, Ito, Abe, et al., 1998; Narici, Modena, Opsomer, Pizzella, Romani, Torrioli, et al., 1991; Penfield & Boldrey, 1937; Tamè, Braun, Lingnau, Schwarzbach, Demarchi, Li Hegner, Farnè, & Pavani, 2012; see also Di Noto, Newman, Wall, & Einstein, 2013, for a discussion on potential differences in the representation of the male and female body in the somatosensory cortex).

One might, however, speculate about whether the phantom limb sensations originate solely from a reorganization of the somatosensory cortex or whether instead they also require the involvement of further neural representations in the brain. For example, the monitoring of efference copy signals or motor commands (e.g., Ramachandran & Hirstein, 1998), the neural substrates responsible for the body schema, and even representations of the body acquired by direct observation (e.g., Brugger, Kollias, Muri, Crelieu, Hepp-Reymond, & Regard, 2000) might all be involved in mediating this striking phenomenon. The report of bilateral activation (as measured by fMRI) of premotor and parietal cortex (BA 6, 7, 8 and intraparietal sulcus), but not of somatosensory cortex and primary motor cortex, in a patient whose limbs were congenitally absent when executing phantom movements, might help to support such a view (Brugger et al., 2000). If future results do indeed confirm the involvement of higher-order brain areas in phantom limb sensations, this would certainly help to confirm the view that tactile consciousness requires the activation of areas beyond just the somatosensory cortex.

In conclusion, the data that have emerged from studies of those patients whose limbs have been amputated appear to suggest that the consciousness of tactile stimuli does not necessarily require the integrity of the tactile receptors on the skin. That is, the neural representation of the body in the brain is sufficient to elicit an awareness of tactile stimuli in the absence of its physical counterpart (e.g., the limbs themselves). This might be related to the fact that tactile stimuli can be referred to locations on the body in external space (e.g., Gallace & Spence, 2005; Kitazawa, 2002; Yamamoto & Kitazawa, 2001). The evidence also suggests that the neural networks that code for the position of the stimuli across the skin, and which sustain a somatosensory representation of the body, appear to have a stable spatial organization (described by Melzack, 1992, 2001, as a “neurosignature”). That is, despite the reorganization of the somatosensory cortex that occurs after amputation (and which is caused by the appropriation of the neural representation of the amputated region by the neural representation of cortically adjacent areas of the body), conscious sensations are still referred to the region previously occupied by the representation of the amputated limb (e.g., Pons et al., 1991; Ramachandran et al., 1992a, b).

4.6.2 A rabbit on the skin: The cutaneous saltation illusion

Our conscious perception of tactile stimuli can be influenced by the subsequent presentation of tactile information. For example, the perceived location of a stimulus delivered on the skin can be shifted toward the location of a rapidly delivered subsequent stimulus (e.g., Flach & Haggard, 2006; Geldard, 1975, 1982; Geldard & Sherrick, 1972, 1983; Goldreich, 2007; Goldreich & Kanics, 2003, 2006; Warren, Santello, & Helms Tillery, 2010). That is, if five taps are presented close to the wrist, followed by five taps at the center of the forearm, and then another five taps from close to the elbow, participants often report the taps to have been uniformly distributed along the arm, rather than at their correct physical locations (see Figure 4.2; e.g., Geldard & Sherrick, 1972). Note, however, that in order to elicit this perceptual mislocalization the stimuli in the sequence must be separated by a temporal interval of about 70–150 ms (e.g., Geldard, 1975, 1982). Given that the sensation elicited by the sequential presentation of the stimuli on the skin has frequently been described in terms of a series of taps “hopping” across the surface of the skin, the phenomenon has come to be known as “cutaneous saltation” or “cutaneous rabbit” illusion (e.g., Geldard & Sherrick, 1972; see also Bremer, Pittenger, Warren, & Jenkins, 1977; Lockhead, Johnson, & Gold, 1980; Shore, Hall, & Klein, 1998; for reports of a similar phenomenon in audition and vision, respectively).⁵ Importantly, the illusory tactile sensations elicited in this way turn out to be indistinguishable from the veridical sensations produced by real stimuli applied to the skin, either at the perceptual, or at the neural level (i.e., as measured by means of fMRI; e.g., Blankenburg, Ruff, Deichmann, Rees, & Driver, 2006). It is also relevant to mention here that using LEDs in order to mimic the “hopping” percept has been demonstrated to strengthen the illusion, whereas flashing

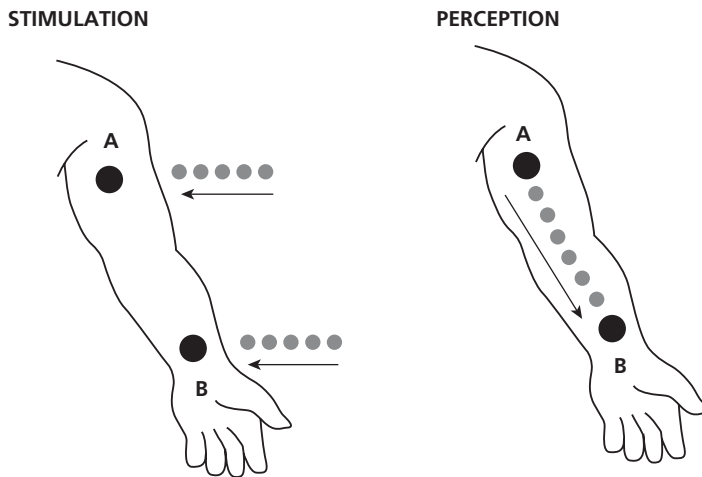


Fig. 4.2 Sequence of tactile stimuli that, if delivered at the correct rate, may give rise to the cutaneous rabbit illusion.

⁵ The illusion is thought to be due the consequence of two fundamental perceptual distortions, the underestimation of interstimulus distance, and the overestimation of interstimulus time (see Goldreich, 2007, for a Bayesian model able to describe and replicate this illusion taking into consideration also the observer's prior expectations).

lights at the discrete tactile stimulation sites weakens it (Yao, Simons, & Ro, 2009). That is, the awareness of an illusory touch in an unstimulated location (i.e., a mislocalization of touch) can result from the simultaneous presentation of visual information (see also Asai & Kanayama, 2012, for the report that a flash of light can enhance or attenuate the cutaneous rabbit illusion depending on its spatiotemporal congruency with the cutaneous signals).

The occurrence of cutaneous saltation (as well as of the other phenomena described in this section) leads to a more detailed consideration of the question regarding the “where and when” of tactile consciousness (and the close relation between the two). Indeed, the stimuli presented early on in the sequence can be consciously reported in a location where they were not physically presented. Even more interestingly, our conscious perception of them seems to be influenced by stimuli that have not yet occurred (i.e., being presented later in the sequence; cf. Dennett, 1991, on this point). It is therefore not surprising that a number of researchers have attempted to identify the mechanism responsible for the phenomenon (e.g., Geldard, 1975, 1982; Geldard & Sherrick, 1972, 1983; Eimer, Forster, & Vibell, 2005).

The fact that saltation on the limbs is more pronounced in the longitudinal direction (i.e., from the elbow toward the wrist) than in the lateral direction, and that it does not occur when the tactile stimuli are presented to non-adjacent regions of the skin (i.e., from the hand to the foot), have been taken to suggest that the cutaneous rabbit illusion might be constrained by the anatomical organization of the somatosensory cortex (e.g., Geldard, 1982; Geldard & Sherrick, 1983). In particular, it has been proposed that the saltation illusion is determined by local interactions taking place between tactile representations at early stages of information processing (e.g., in the somatosensory cortex; e.g., Cholewiak, 1999; Geldard, 1982; see Chapter 2 for a description of somatosensory organization in the brain).

However, Eimer et al. (2005) have demonstrated that saltation in touch can also be observed under conditions in which a number of the stimuli are presented to each arm (i.e., to non-contiguous regions of the somatosensory cortex), and when the focus of their participants’ attention was maintained at the same location. On the basis of their results, Eimer and colleagues went on to conclude that the saltation illusion is not necessarily produced at an early stage of information processing (i.e., at the level of the somatosensory cortex), and that it might not even be related to attention, as has been argued by certain researchers (cf. Kilgard & Merzenich, 1995). Instead, they proposed that the phenomenon is likely to arise in higher-order brain areas, such as the secondary and posterior parietal somatosensory areas, where there are a large number of neurons with bilateral receptive fields (e.g., Iwamura, Iriki, & Tanaka, 1994). This claim might be further strengthened by Miyazaki, Hirashima, and Nozaki’s (2010) observation that the cutaneous rabbit can “hop out of the body” onto an external object held by the participant. That is, the participants in this latter study received a series of taps via a stick that was laid across the tips of their index fingers. They reported perceiving the illusory taps in the space between the actual stimulus locations, namely along the stick. These authors concluded that the effects of the cutaneous rabbit illusion involves not only somatotopic representation but also higher-order representations that extend beyond the physical boundaries of our body. Although further research is needed in order to better understand this striking phenomenon, the presence of the saltation illusion in the tactile modality strengthens the suggestion that conscious access to information regarding a given tactile stimulus, always follows the processing of *spatial* information in the brain. Indeed, in the cutaneous rabbit illusion, the stimuli that happen to be presented earlier in the sequence, when consciously detected, are referred to positions that are determined *only after* the presentation of the subsequent stimuli (and therefore after spatial interactions have taken place between the earlier and later stimuli in the sequence). Finally, the results that have emerged recently from

this study of the illusion also suggest that by itself the sole activation of the somatosensory cortex might not be responsible for the conscious awareness of tactile information (e.g., Eimer et al., 2005; Miyazaki et al., 2010; see also Blankenburg et al., 2006; Libet, Alberts, Wright, & Feinstein, 1967; Pockett, 2002).

4.7 Tactile hallucinations: When touch is in the mind of the beholder

So far in this chapter, we have addressed questions related to awareness of information that is actually presented on the body surface, or that at least follow some sort of tactile stimulation (such as in tactile illusions). However, there are situations in which an awareness of touch is elicited without a stimulus actually being delivered. This is the case of tactile hallucinations. It is not surprising to find that very little research has been conducted on the topic of tactile hallucinations or delusions, as compared to the much larger body of research dedicated to visual hallucinations (e.g., Bressloff, Cowan, Golubitsky, Thomas, & Wiener, 2001; Kluver, 1966; cf. Brown, Skehan, Chapman, Perry, McKenzie, Lloyd, Babbs, Paine, & Poliakoff, 2012). Note, though, that many of us have probably experienced some sort of hallucination in the tactile modality. For example, who has never felt those tingling, tickly sensations occurring spontaneously all over the body in the absence of actual stimulation? Despite the fact that in some cultures they are considered as a sign of good luck (in Italy, for example, they are thought to anticipate the arrival of money), whenever we experience them we are immediately drawn to ask ourselves where they come from, given that no actual stimulus is present on the part of the body where these sensations arise (see Michael & Naveteur, 2011, for an investigation into the origins of these experiences). So what does the extant research have to say about awareness of sensations that are not elicited by external stimuli?

Reported cases of tactile hallucinations vary from more basic tactile sensations such as imaginary itches (Darwin, 1796), formication (i.e., the abnormal sensation as of insects crawling in or upon the skin; cf. Caporael, 1976; Matossian, 1982), pinching, rubbing (Regis, 1906), and having the skin covered in fur (Storring, 1907), to far more complex perceptual experiences, such as being kissed, having someone lying by one's side, and more or less bizarre sexual experiences (Kraepelin, 1919; see Berrios, 1982, for a review; see also Grimby, 1993 for the report of tactile hallucinations in 6% of cases in elderly people following bereavement).

Examples of tactile hallucinations, such as the perception of crawling sensations on the skin were also an important aspect of the famous "Salem witch trials" (a series of hearings and prosecutions of people accused of witchcraft in colonial Massachusetts, between February 1692 and May 1693; these facts have been suggested to be related to "ergotism" a clinical condition determined by ergot poisoning and leading to a number of symptoms such as crawling sensations in the skin, tingling in the fingers, vertigo, tinnitus aurium, headaches, disturbances in sensation, hallucination, and painful muscular contractions; see Caporael, 1976; see also Woolf, 2000). In a number of different cases, tactile hallucinations have been associated with an organic state such as brain injury, dementia, hypophyseal tumor, and diabetes, rather than with a non-organic psychosis (Skott, 1978). For example, in a sample of 46 patients affected by tactile hallucinations (namely delusions of infestation), Skott found that about 50% exhibited clinical signs of an organic brain syndrome, 61% had pathological EEGs, and 12% had malignant disease (i.e., carcinoma).

One case of tactile (as well as visual) hallucinatory sensations following brain damage was reported by Halligan, Marshall, and Ramachandran (1994) in a patient following right hemisphere stroke. The patient exhibited a number of hallucinations (compatible with a diagnosis of Charles Bonnet Syndrome; e.g., Morsier, 1936; Schultz & Melzack, 1991), together with a

moderate left-sided neglect and left visual field deficits, in the first few days after hospitalization. These symptoms progressively receded and then completely disappeared approximately a year after the first observation. The hallucinations were primarily visual and involved human figures, animals, and aerial views. On different occasions, the patient also reported tactile sensations related to the object of her hallucinations. For example, she not only experienced the presence of a dog (actually one of her dogs that had died many years earlier), but also reported the sensation that the dog's fur was wet to touch, just as when he had come back to her following a walk in the rain (p. 466). She also reported the tactile feeling associated with poking her husband's arm in order to wake him up (p. 466, Halligan et al 1994).

The patient's lesion had affected the right temporal pole, caudate nucleus, lower basal ganglia, insular cortex, putamen, and posterior frontal cortex. On the basis of various considerations, Halligan and his colleagues ruled out the possibility that the patient's hallucinations were due to a psychotic state or to a lack of central control. By contrast, they suggested that they were likely determined by the brain damage suffered by the patient and, in particular, by a form of sensory deprivation due to a disconnection between higher-order and sensory brain areas. Note, however, that this interpretation was only based on the visual hallucinations reported by the patient. In fact, Halligan and his colleagues didn't comment on the possible cognitive and neural mechanisms of the tactile hallucinations that were reported by their patient. If visual hallucinations are produced when visual association areas, deprived of their normal input (due to lesions of the connections between higher visual areas such as V4 and sensory visual areas such as area 17), fire spontaneously, one might wonder whether a similar mechanism could also cause the tactile hallucinations reported here. We believe, however, that there is another potential interpretation that ought to be considered.

Neuroimaging studies have revealed that both the posteroventral insula (a structure that was also damaged in the patient studied by Halligan and his colleagues, 1994) and perirhinal cortex are involved in the storage of tactile information regarding haptically explored stimuli (e.g., Bonda, Petrides, & Evans, 1996; see Gallace & Spence, 2009, for a review). It may be that tactile (as well as visual) hallucinations are caused by the faulty activation of those brain areas responsible for tactile memories. Eventually, a misfiring of the circuit that sustains tactile memories (and that includes the somatosensory cortex as well as areas responsible for the active exploration of the stimuli; see Gallace & Spence, 2009) could, at least in part, explain the hallucinatory tactile phenomena reported by Halligan and his colleagues. Alternatively, however, the tactile component of the hallucinations seen in this patient might simply result from the effect of higher-order visual areas upon those responsible for the processing and/or storage of tactile information. In fact, tactile sensations can be elicited, under certain conditions, by nothing more than visual or even auditory stimulation (e.g., Durgin et al., 2007; Kitagawa & Igarashi, 2005; see also section 4.6.2).

Since the advent of neuroimaging, a few studies have attempted to investigate the involvement of different brain structures in tactile hallucinations. In particular, the majority of efforts have been directed at analyzing a form of visuotactile delusion known as *delusional parasitosis* (e.g., Huber, Karner, Kirchler, Lepping, & Freudenmann, 2008; Musalek et al., 1989; see de Leon, Antelo, & Simpson, 1992, for an early review). Delusional parasitosis is a syndrome characterized by the conviction (accompanied by reports of tactile and sometimes visual sensations) that one's skin is infested with small creatures. In one of the first attempts to determine the neural correlates of this condition, Musalek and colleagues (1989) studied ten unmedicated patients who reported delusions of parasitosis using single-photon emission computed tomography (SPECT) to measure regional cerebral flow. They found a relative reduction of regional cerebral flow in the inferior temporal regions. Following this early study, the majority of the reports accumulated over the

years suggest that delusions of parasitosis commonly occur after damage to subcortical or cortical brain regions, often in the temporoparietal region of the right hemisphere (e.g., Adunsky, 1997; Blanke, 2008; Blasco-Fontecilla et al., 2005; De Leon et al., 1992; Flynn et al., 1989; Maeda et al., 1998; Nagaratnam & O’Neile, 2000; Narumoto et al., 2006; Safer et al., 1997; Takahashi, Ozawa, Inuzuka, Harada, Hanihara, & Amano, 2003).

More recently, Huber et al. (2008) used MRI in order to determine whether structural lesions of brain regions could be found in patients with delusions of parasitosis. On the basis of their findings, they suggested that structural lesions in the striatum, predominantly the putamen, might account for this syndrome at least in those patients with a medical condition (but not in those with a pre-existing psychiatric illness). Even more relevant to the topic of the present chapter is the observation by the authors that the putamen contains bimodal cells with visual and tactile receptive fields, which help to encode the location of stimuli mainly near the face (e.g., Graziano & Gross, 1994; Gross & Graziano, 1995). On the basis of these considerations, they claimed that the itching and tactile hallucinations, as well as somatic delusions seen in patients, were mediated through a striato-thalamo-parietal network.

Neuroimaging studies in humans have revealed (using diffusion tensor imaging (DTI) tractography) that the putamen is interconnected with the prefrontal cortex, primary motor area, primary somatosensory cortex, supplementary motor area, premotor area, cerebellum and thalamus (Leh, Ptito, Chakravarty, & Strafella, 2007). Based on this observation, we believe that the primary somatosensory cortex may well be involved in hallucinations such as those reported in delusions of parasitosis. One might wonder, however, whether the role of this structure in eliciting the phenomenon is determined by subcortical to cortical (by means the direct connections of SI with the putamen) or cortical to cortical activation (mediated by the involvement of areas of the frontal and/or parietal cortex). Note that these two explanations are not necessarily mutually exclusive.

4.8 The neuropsychology of tactile consciousness: Numbness, neglect, and extinction

Dissociations between the implicit and explicit perception of external events (e.g., residual functioning in the absence of explicit knowledge) have been extensively described in the last century in both neurologically normal participants and in those patients suffering from neurological impairment (see Berti, 2002; Bridgeman, 2000; Milner & Goodale, 1995; Nakamura, Oga, & Fukuyama, 2012; Pisella & Rossetti, 2000; Rossetti, 1998; Vallar, Burani, & Arduino, 2010; Van Vleet & Robertson, 2009; Weiskrantz, 1991, 1996). The presence of dissociations in brain-damaged patients is of great importance in terms of the light it may shed when investigating the neurological substrates of the cognitive functions and, in the specific case highlighted in this book, of the *conscious* processing of tactile events (e.g., Dunn & Kirsner, 2003; Lahav, 1993; Vallar, 1999).

The phenomenon of “blindsight” in brain-damaged patients is one of the most frequently reported examples of a dissociation between implicit and explicit information processing and has frequently been considered as a possible means of investigating the neurological substrates of visual consciousness in humans (e.g., Azzopardi & Cowey, 1998; Cowey & Stoerig, 1995; see Leopold, 2012, for a recent review; see also Kentridge, 2012, for the neural substrate of blindsight in monkeys). The word “blindsight” clearly highlights some characteristics of certain patients affected by lesions of the primary visual striate cortex (i.e., lesions to area V1). Specifically, these patients are unable to report the presence of stimuli presented within the area of the visual field affected by the lesion. Surprisingly, however, if asked to point to the location of the stimulus (under conditions of forced choice) they are often able to correctly execute a hand or eye movement

toward that location (see Stoering & Cowey, 1997; Weiskrantz, 1986). Note that other properties of the stimuli, such as their wavelength (i.e., color), have also been reported to be processed unconsciously in patients with lesions to their primary visual areas (e.g., Stoering & Cowey, 1989, 1992). The general consensus among researchers in the field is that the spared abilities of patients suffering from blindsight are not simply attributable to intact residual areas of V1 (e.g., Leopold, 2012; Weiskrantz, 1996).

A similar dissociation between impaired explicit report of a stimulus and the spared processing of certain qualities of that stimulus (such as its spatial location) has also been reported in touch (e.g., Brochier, Habib, & Brouchon, 1994; Imanaka, Kita, & Suzuki, 2002; Paillard, Michel, & Stelmach, 1983; Rode, Rossetti, & Boisson, 1995; Rossetti, Rode, & Boisson, 2001; Volpe, Ledoux, & Gazzaniga, 1979). For example, Paillard et al. reported the case of a brain-damaged patient who was unable to detect the presence of tactile stimuli presented on his arm or to localize their position verbally, but who was able to point fairly accurately to the location that had been stimulated. On the basis of its apparent similarity with blindsight in vision, this phenomenon was initially given the name “blind-touch” by Paillard and his colleagues. Interestingly, the patient studied by Paillard et al. was able to point “spontaneously” to the locus of stimulation (that is, without the necessity of using a forced choice response procedure, such as typically required when testing blindsight patients). Although the cerebral lesion affecting Paillard et al.’s patient involved the left parietal area, the authors refrained from attributing a causal role to damage in this specific brain area. Instead, they concluded that any attempt to identify the neural mechanisms underlying the dissociation between localization and identification, “regardless of the sensory modality,” must take into account the contribution of motor processes in the mapping of sensorimotor space.

A further case illustrating a dissociation between localization (where) and identification (what) was reported by Brochier et al. (1994). They described a patient with a complete loss of somesthetic sensitivity in his left arm as a consequence of damage to the primary somatosensory area in the right hemisphere. Surprisingly, two months after his hospitalization, the patient was able to point correctly to stimulated locations on the deafferented limb even when blindfolded. Brochier et al. concluded that the accurate performance exhibited by their patient could have been mediated by the “covert” processing of somesthetic information that unconsciously affected the sensorimotor control of hand movements.

Following on from these early observations, several subsequent cases of neurological patients exhibiting characteristics similar to those described by Paillard et al. (1983) have been reported in the literature under a variety of different names, such as blind proprioception (e.g., Volpe et al., 1979), blind-touch, central deafferentation (e.g., see Paillard, 1999), and numbsense (e.g., Weiskrantz, 1997). All of these terms have been used to define the dissociation between explicit conscious report and the implicit processing of tactile information in humans (e.g., Paillard et al., 1983; Rode et al., 1995). The fact that people affected by numbsense can correctly localize the position of the stimuli but are unable to consciously identify their characteristics might suggest that, by itself, spatial processing is necessary but not sufficient to promote the access to consciousness of tactile information (though see Harris, Karlov, & Clifford, 2006, for the claim that the localization of a tactile stimulus follows its conscious detection; cf. Kitazawa, 2002, for a conflicting account).

4.8.1 Spatial neglect and extinction

Neurological patients affected by unilateral spatial neglect often fail to report and/or explore stimuli presented on the side of space contralateral to their brain lesion (i.e., in contralesional

space), with respect to an egocentric reference frame such as the mid-sagittal plane of the body trunk (e.g., Bisiach & Vallar, 2000; Corbetta & Shulman, 2011; Vallar, 1998; though note that other frames of reference may also be affected by the syndrome; e.g., Gallace, Imbornone, & Vallar 2008; Vallar, 1997). The deficit affecting unilateral spatial neglect patients is not only assessable by means of clinical and laboratory procedures, but is also clearly evident in a wide range of everyday activities. In particular, these patients may not pick up food from the left side of their plates, may comb their hair, shave, and apply cosmetics only on one side of their face/body (e.g., Bisiach & Vallar, 1988; see Figure 4.3, for the drawing of a neglect patient that illustrates the lack of details in the contralesional side of his painting after the stroke). If addressed by the examiner from the contralesional side (i.e., left) these patients may also fail to respond, or else may look for the speaker in the ipsilesional (i.e., right) side of the room.

Although the specific intrahemispheric localization of the areas involved in unilateral neglect is still a matter of some debate (see Karnath et al., 2001; Molenberghs, Sale, & Mattingley, 2012; Oliveri & Vallar, 2009; Suchan, Rorden, & Karnath, 2012; Vallar, 2001), the lesion sites that have been more frequently associated with spatial disorders include the right inferior parietal lobe, the right superior temporal gyrus, and the right premotor cortex (e.g., Karnath et al., 2001; Mort, Malhotra, Mannan, Rorden, Pambakian, Kennard, et al., 2003; Vallar, 2001). Furthermore, lesions to subcortical structures such as the thalamus, the basal ganglia, and the subcortical white matter have also been associated with spatial neglect (see Harciarek, Williamson, Burtis, Haque, & Heilman, 2012; Vallar & Perani, 1986).

Neurological patients affected by extinction are able to detect a stimulus presented in isolation in the ipsi- or contralesional side of space (and/or of their body) but often fail to detect the same stimulus when it is delivered to the contralesional side of the space or of their body under conditions of double stimulation (i.e., when one stimulus on the left and another on the right are presented simultaneously; e.g., Barbieri & De Renzi, 1989; Bender, 1952; Bisiach, 1991; Riddoch,

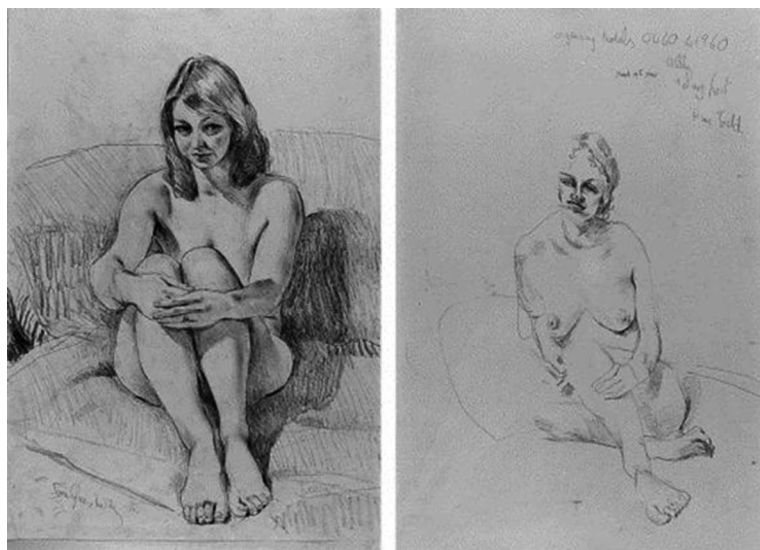


Fig. 4.3 Drawings by the artist Tom Greenshields made before (left) and after (right) a stroke. Reproduced from I. H. Robertson, and P. W. Halligan, *Spatial neglect: A clinical handbook for diagnosis and treatment*, © 1999, Psychology Press, with permission.

Rappaport, & Humphreys, 2009). There appears to be a double-dissociation between neglect and extinction (e.g., Barbieri & De Renzi, 1989; Vossel, Eschenbeck, Weiss, Weidner, Saliger, Karbe, & Fink 2011) but, just as for neglect, extinction is more frequent after right (rather than left) hemisphere damage (e.g., de Haan, Karnath & Driver, 2012; Goodrich & Ward, 1997; Vallar, Rusconi, Bignamini, Geminiani, & Perani, 1994).

Extinction has also been reported to affect the detection of *tactile* stimuli when both sides of the body are stimulated concurrently (e.g., Vallar et al., 1994).⁶ In certain cases, patients suffering from tactile (or somatosensory) extinction, although able to perceive that something has been presented to the contralesional hand, are unable to report on the qualities associated with that sensation (e.g., Schwartz, Marchok, & Flynn, 1977). Furthermore, under conditions of active tactile stimulation (i.e., haptic perception), patients may be aware of the presence of an object placed in the contralesional hand, and can explore it with active movements, but are unable to identify it (e.g., Maravita, 1997). That is, while haptic exploration can be preserved in patients with extinction, tactile information regarding an object's identity (gathered by means of the patient's movements) may not necessarily have access to conscious levels of information processing.

Note that several findings now suggest that somatosensory extinction, just as in vision, is not exclusively determined by peripheral sensory mechanisms. In particular, the following observations help to support the claim that tactile as well as visual extinction is determined by damage to higher-order levels of information processing (e.g., Sambo, Vallar, Fortis, Ronchi, Posteraro, Forster, & Maravita, 2012; Vallar, 1997; Vallar, Bottini, Rusconi, & Sterzi, 1993; see also Magosso, Zavaglia, Serino, di Pellegrino, & Ursino, 2010): Contralesional extinction may be made more severe if the patient who is affected looks toward the ipsilesional side of his/her body (e.g., Larmande & Cambier, 1981); The awareness of contralesional stimuli may be improved by looking at, or intentionally moving to the location of tactile stimulation (i.e., when participants *actively* deliver a stimulus to a particular location; e.g., by touching an arm using their index finger; e.g., Halligan, Hunt, Marshall, & Wade, 1996; Halligan, Marshall, Hunt, & Wade, 1997; Vaishnavi, Calhoun, & Chatterjee, 2001); Just as for neglect, extinction is more frequent after right than left hemisphere damage (e.g., Sterzi, Bottini, Celani, Righetti, Lamassa, Ricci, & Vallar, 1993; Vallar, Bottini, Rusconi, & Sterzi, 1993); and finally *crossmodal* contralesional extinction has been reported (i.e., a *visual* ipsilesional stimulus can extinguish a patient's awareness of a contralesional *tactile* stimulus; e.g., Farnè, Iriki, & Ladavas, 2005; Ladavas, di Pellegrino, & Farnè, 1998; Mattingley, Driver, Beschin, & Robertson, 1997; Sambo, Vallar, Fortis, Ronchi, Posteraro, Forster, & Maravita, 2012; see Ladavas & Farnè, 2004, for a review).

Finally, it is important to note that the awareness of tactile information in the case of extinction, as well as in the case of neglect, can be modulated by many different experimental manipulations. In particular, transcutaneous nerve stimulation (e.g., Schröder, Wist, & Hömberg, 2008; Vallar, Rusconi, Barozzi, Bernardini, Ovadia, Papagno, & Cesarini, 1995), neck muscle vibration (e.g., Karnath, Christ, & Hartje, 1993), vestibular caloric stimulation (e.g., Bottini, Paulesu, Gandola, Loffredo, Scarpa, Sterzi, Santilli, Defanti, Scialfa, Fazio, & Vallar, 2005; Karnath, Himmelbach, & Perenin, 2003; Moon, Lee, & Na, 2006; Rubens, 1985), optokinetic stimulation (e.g., Beschin, Cocchini, Allen, & Sala, 2012; Bisiach, Pizzamiglio, Nico, & Antonucci, 1996; Vallar, Guariglia, Nico, & Pizzamiglio, 1997), and prism adaptation (e.g., Bolognini, Casanova, Maravita, & Vallar,

⁶ Note that extinction has been also reported using auditory, olfactory/trigeminal, and even pairs of gustatory stimuli (e.g., Bellas, Novelly, Eskenazi, & Wasserstein, 1988; Bender & Feldman, 1952; De Renzi et al., 1984; see also Sela & Sobel, 2010).

2012; Girardi, McIntosh, Michel, Vallar, & Rossetti, 2004; Rusconi & Carelli, 2012) have all been shown to modulate the awareness of neglected information in right hemisphere brain-damaged patients (see Chokron, Dupierri, Tabert, & Bartolomeo, 2007, for a review). Note that all of these experimental manipulations involve functionally and neuroanatomically distinct underlying neural systems (see Daini, Angelelli, Antonucci, Cappa, & Vallar, 2002; Dieterich, Bucher, Seelos, & Brandt, 1998). Results such as these have been taken to suggest that the common factor underlying the effectiveness of such experimental manipulations may be the fact that they all affect the “higher-order” levels of information processing required to support the egocentric representation of external space (e.g., Nico, 1999; Vallar, Antonucci, Guariglia, & Pizzamiglio, 1993).

Taken together, these observations would appear to suggest that the integrity of higher-order (likely amodal or multisensory) *spatial* representations may play an important role in our awareness of tactile information. Further support for this claim comes from the results of studies on multisensory processing in patients suffering from neglect and extinction (e.g., Jacobs, Brozzoli, & Farnè, 2012; Mattingley et al., 1997; cf. Ortigue, Jabaudon, Landis, Michel, Maravita, & Blanke, 2005, for the report of a patient suffering from a multisensory form of alloesthesia). Indeed, it has been reported that visual stimuli presented near a patient’s ipsilesional hand can give rise to in the extinction of concurrently presented stimuli delivered to the contralesional hand (e.g., Mattingley et al., 1997; see also Farnè, Pavani, Meneghello, & Ladavas, 2000; Sarri et al., 2006). Similarly, visual information regarding the position of a tactile stimulus has been shown to improve somatosensory perception in those brain-damaged patients affected by hemisensory deficits such as neglect and extinction (e.g., Halligan et al., 1996, 1997; Newport, Hindle, & Jackson, 2001; see Forster & Eimer, 2005, for an insight into the neural correlates of such effects explored by means of measuring event-related brain potentials; cf. Johansson, 2012). The awareness of tactile information therefore appears to be a multisensorially modulated phenomenon, one that is related to the processing of information in other sensory modalities (and likely involves the mediation of multisensory brain areas; e.g., Forster & Eimer, 2005).

4.8.2 Implicit processing of tactile information in neglect and extinction

Interestingly, patients affected by visual neglect and extinction are able to process contralesional visual information to some extent, although they need not be aware of it (e.g., Driver & Vuilleumier, 2001; Köhler & Moscovitch, 1997; Marzi, Girelli, Natale, & Miniussi, 2000; Wallace, 1994). A number of studies have reported that left-sided *visual* information may be processed up to the level of lexical and semantic content and hence influence a patient’s performance in several tasks, including forced choice (i.e., such as under conditions in which patients are required to choose between two pictures that only differ in terms of their right side; e.g., Bisiach & Rusconi, 1990; Marshall & Halligan, 1988), semantic and perceptual priming (e.g., Berti & Rizzolatti, 1992; Ladavas et al., 1993), numerical processing (e.g., Zorzi, Bonato, Treccani, Scalabrini, Marenzi, & Priftis, 2012), lexical decision and categorization (e.g., Arduino et al., 2003; Ladavas et al., 1997), free association (e.g., Vallar et al., 1996), and visuomotor tasks (e.g., Behrmann & Meegan, 1998).

The results of a few studies have demonstrated that patients with neglect and extinction can also implicitly process (up to a certain level) tactile stimuli presented to the contralesional side of their body, which they are not explicitly able to report (e.g., Aglioti, Smania, Moro, & Peru, 1998; Berti, Oxbury, Oxbury, Affanni, Umiltà, & Orlandi, 1999; Eimer et al., 2002; Maravita, 1997; cf. Mancini, Bricolo, Mattioli, & Vallar, 2011). For example, Angelo Maravita described the case of a right-hemisphere brain-damaged patient exhibiting tactile extinction and neglect who was unable

to report any of the qualities of objects held in his contralesional hand when another object was simultaneously presented in his ipsilesional hand. Critically, however, when the patient was asked to compare the size of two spheres (one presented to each hand), his judgments were biased by the size of the sphere previously held in his contralesional hand, although he had been unable to explicitly report its presence versus absence. Indeed, note here that in neurologically normal participants, the judgment of the size of objects held in one hand can also be influenced by the size of an object held previously in the same hand (see Uznadze, 1966; cf. Maravita, 1997). Maravita's patient had a lesion that included the lingual and fusiform gyri, the retrosplenial area, the angular gyrus, and part of the superior parietal lobule, but not the primary somatosensory cortex. On the basis of these results, Maravita concluded that the lesion observed in his patient impaired the conscious perception of contralesional tactile stimuli during bilateral stimulation but not pre-conscious sensory processing, thought to be mediated by the lower-level somatosensory areas that were spared by the lesion.

A difference between implicit and explicit tactile information processing in brain-damaged patients was also described by Berti et al. (1999). They described a patient with right occipitoparietal damage who suffered from neglect and tactile extinction, who was unable to name objects presented to his contralesional hand when another object was simultaneously presented to his ipsilesional hand. Interestingly, this patient was able to make above chance same/different judgments regarding the two objects presented in each hand. Berti et al. concluded that in their patient, 3D tactile representations might have been accessed implicitly and pre-attentively.

It is, however, important to note here that in studies of *visual* neglect, it has been proposed that the difference between more explicit kinds of tasks (e.g., identification) versus more implicit tasks (i.e., forced choice, priming, same/different judgments) may be related to the "quality" of the representation involved in the performance of the different tasks (e.g., Behrmann & Meegan, 1998; Volpe et al., 1979). Specifically, a comparatively more degraded representation may be sufficient to support same-different judgments or priming effects (e.g., Ládavas et al., 1993, 1997), but may be insufficient for tasks such as identification or reading. Different levels of representation may therefore support tasks such as, identification, categorization, lexical decision, and reading, on the one hand, versus same-different judgments and priming on the other. The latter tasks may not require perceptual awareness, and therefore be comparatively preserved in patients suffering from left neglect (e.g., Berti, 2002). Following on from these arguments, it seems plausible to think that the 3D tactile representations of the haptically explored objects accessed by the patient studied in Berti et al.'s (1999) study was only able to support same/different judgments (a less demanding task), but not identification (a putatively more demanding task).

Another important result to emerge from Berti et al.'s (1999) study relates to the role played by the spatial frame of reference used in the tactile tasks. Specifically, the researchers observed that extinction always affected the contralesional hand, regardless of the position of that hand in space (i.e., no matter if the hands were placed in an uncrossed or crossed hands posture; but see Aglioti, Smania, & Peru, 1999, for the report of a beneficial effect of crossing the hands on the detection of tactile stimuli presented to the contralesional hand of those patients suffering from tactile extinction). It is important to highlight here that a tendency for a decrement in haptic recognition performance was also reported when the ipsilesional (i.e., unaffected) hand was tested in the contralesional side of space (cf. di Pellegrino et al., 1997). Berti et al. concluded that their patient might have had a deficit involving both a body-centered and an extrapersonal frame of reference used to code and consciously represent haptic information. The damage to the former system (thought to have its neurological substrate in neurons responding to stimuli presented on the hands and with receptive fields that move together with change in hand position; e.g., Graziano,

Yap, & Gross, 1994) would explain his extinction of stimuli presented on the contralesional hand regardless of its spatial position. By contrast, the damage to the latter system would explain the worsening performance seen when the ipsilesional hand was placed in the contralesional side of space.

This set of observations clearly suggests that the neuronal systems involved in the representation of spatial information (and that have their substrate in the temporoparietal regions of the brain), are of great importance for the conscious perception of tactile stimuli. Note also that the pure form of tactile agnosia (i.e., an impairment in tactile identification without deficit of elementary perceptive qualities of physical objects), has been reported after lesions of the posteroparietal regions of the right hemisphere (e.g., Gerstmann, 2001).

In order to further strengthen the claim regarding the importance of *spatial processing* for the awareness of tactile events, it is worth noting here that a large body of evidence has now been reported showing that awareness of tactile information in patients suffering from neglect and extinction may vary as a function of the posture adopted (e.g., Peru, Moro, Sattibaldi, Morgant, & Aglioti, 2006). In particular, Smania and Aglioti (1995) tested the detection of tactile stimuli in right-hemisphere brain-damaged patients and normal participants with either their hands in an anatomical or crossed posture (see also Aglioti, Smania, & Peru, 1999; Bartolomeo, Perri, & Gainotti, 2004). Surprisingly they found that while crossing the hands impaired the performance of neurologically normal participants (see also section 4.8.1), the performance of brain-damaged patients improved by more than 30% when their hands were crossed. Smania and Aglioti proposed that their participants' ability to detect tactile stimuli relied on both a somatotopic and an extrapersonal spatial representation. Consequently, the right hemisphere brain damage may have impaired the left part of both representations, resulting in a deficit of awareness for information presented on the left side of the body and/or space (e.g., Aglioti, Smania, & Peru, 1999; Smania & Aglioti, 1995; see also Bisiach, Luzzatti, & Perani, 1979; Bisiach, Rusconi, Peretti, & Vallar, 1994; Gallace, Imbornone, & Vallar, 2008; Pouget & Driver, 2000; Pouget & Sejnowski, 2001).

A further investigation exploring the frames of reference involved in the awareness of tactile information was undertaken on a right hemisphere brain-damaged patient suffering from a relatively pure form of tactile extinction by Tinazzi, Ferrari, Zampini, and Aglioti (2000). The patient in this particular study had to try and detect the presence of single or double tactile stimuli delivered to both hands. The patient was tested while assuming different hand postures: palms-up or palms-down, placed either in front or behind their body, and either with the hands uncrossed or crossed. The results revealed that, as expected, the left-sided stimuli were extinguished when stimuli were presented to both hands under conditions of double simultaneous stimulation, but more surprisingly the leftmost stimuli were also extinguished when presented to a single hand (on its left or right side) or on a single finger (see also Moscovitch & Behrmann, 1994). On the basis of these results, Tinazzi et al. went on to conclude that the reference systems used for coding tactile stimuli can be scaled dynamically (and rapidly) from the corporeal midline to other parts of the body, as a function of the sensorimotor demands of the external environment.

Taken together, these data highlight the importance of the frame of reference or spatial representation used in order to compute information regarding tactile stimuli. Specifically, while implicit processes appear to be sustained by lower level neural representations, perhaps based on a somatotopic frame of reference (e.g., Penfield, 1950; Romo, Hernandez, Zainos, & Salinas, 1998), more explicit forms of processing may well require the integrity of higher-level neural representations based on body-centered or allocentric frames of reference (e.g., Vallar, 1997; Vallar, Lobel, Galati, Berthoz, Pizzamiglio, & Le Bihan, 1999). Note, though, that an important role in the choice of the most appropriate reference frame (i.e., centered on the head, hand, space, object, or even

tool) to be used for the explicit processing of tactile information seems to be related to the sensorimotor characteristics of the to-be-performed tasks (see Holmes et al., 2004; Tinazzi et al., 2000).

The neurological substrates of implicit and explicit forms of information processing seem, in part, to overlap. Specifically, the implicit processing of tactile information requires the integrity of the somatosensory cortex, while the awareness of such information requires the integrity of both the somatosensory cortex and the posterior parietal cortex, where tactile information is converted and transformed accordingly to a specific spatial frame of reference (e.g., Andersen, 1997; Andersen et al., 1997; Gross & Graziano, 1995).

Neuroimaging research has demonstrated that the denial and lack of awareness of *motor* impairment in right-brain damaged patients is associated with cortical areas related to the programming of motor behavior, such as Brodmann's premotor areas 6 and 44, area 4 and the somatosensory cortex (Berti, Bottini, Gandola, Pia, Smania, Stracciari, Castiglioni, Vallar, & Paulesu, 2005; see Chapter 2, Figure 2.6 for a representation of the Brodmann areas). This data has been taken to suggest that the monitoring and consciousness of events is not a prerogative of a central executive that sits at the top of a hierarchically organized network of structures, but rather a function that is implemented in the same neural network responsible for the processes that have to be monitored (e.g., Berti et al., 2005).

The evidence that has emerged from the study of those unfortunate patients suffering from numbness, neglect, and extinction, therefore suggests that awareness of tactile events may be implemented in the same neural network responsible for the sensory processing of those events. But it also suggests that higher-order areas, involved in the processing of amodal or multisensory qualities of the stimuli as well as of spatial information, might also be necessary. This claim, however, does not necessarily imply that the consciousness of tactile events requires a central executive monitoring system, but only that higher-order associative areas, not solely related to the sensory processing of tactile information, seem to be involved in the awareness of tactile information (e.g., Eimer et al., 2002). Further studies, and in particular, neuroimaging studies of both patients with lesions (and who are affected by tactile neglect/extinction or numbness) and neurologically normal participants (perhaps tested after the induction of a temporary brain lesion using transcranial magnetic stimulation), need to be conducted in order to investigate the neurological substrates responsible for awareness of tactile events.

4.9 The psychophysiology of tactile consciousness

On the basis of previous psychophysiological studies related to the neural substrates of visual consciousness, it has been suggested that the results of activity in primary visual areas (V1) does not directly enter visual awareness (e.g., Crick & Koch, 1990). By contrast, what does enter awareness is some form of neural activity in certain higher visual areas (i.e., anterior to V1; e.g., Crick & Koch, 1990, 1992, 1995). With regard to the tactile modality, it has been reported that several parietal regions outside of the somatosensory cortex participate in the processing of somatosensory information (e.g., Burton, 1986; Burton, MacLeod, Videen, & Raichle, 1997; Penfield & Jasper, 1954; Woolsey, Erickson, & Gilson, 1979). Moreover, psychophysiological studies conducted on animals (rats, monkeys, and cats) have revealed strong top-down influences on activation in S1 during the active performance of a discrimination task (i.e., when an animal actively explores its environment; e.g., Krupa, Wiest, Shuler, Laubach, & Nicolelis, 2004; cf. Lafuente & Romo, 2005, for the report of a lack of covariation between monkeys' perceptual reports of near-threshold tactile stimuli delivered to the fingers and the response of neurons in the primary somatosensory cortex). It should not, therefore, come as much of a surprise to observe that the leading

role of S1 for the awareness of tactile information has only recently begun to be questioned and debated (e.g., Palva, Linkenkaer-Hansen, Näätänen, & Palva, 2005; Preißl et al., 2001; Schubert, Blankenburg, Lemm, Villringer, & Curio, 2006; Schwartz, Assal, Valenza, Seghier, & Vuilleumier, 2005; see also Lafuente & Romo, 2005).

One of the first attempts to investigate the involvement of the somatosensory cortex in the awareness of somatosensation was pursued by Libet et al. (1967). These researchers reported that the averaged evoked response to tactile stimulation could be recorded subdurally from the somatosensory cortex (in patients undergoing neurosurgery for various clinical conditions) even when the stimulus intensity was set below the threshold for producing conscious sensory awareness. However, late components (up to and exceeding 500 ms following stimulus onset) that followed the primary evoked potential were well correlated with sensory awareness and were thus determined to be necessary for the stimulus to be consciously perceived. Libet et al. concluded that the primary evoked potential in S1 is not a sufficient condition for perceptual awareness.

In 2001, a magnetoencephalography (MEG) study by Preißl et al. investigated tactile consciousness in two patients scheduled for neurosurgery to remove brain tumors, who reported a lack of somatosensory sensations. Magnetic imaging revealed early (within an interval of 40 ms from stimulus onset) neural activations in the primary somatosensory cortex in both patients, but the absence of any later activation (in the 60 and 150ms components of the MEG) in either the primary or associative areas (parietal cortex, areas BA 5, 7, and 40). On the basis of these results, Preißl et al. concluded, as had Libet et al. (1967) some years earlier, that areas posterior to S1 are necessary for the conscious processing of somatosensory stimuli (see also Aukstulewicz et al., 2012; Ray, Meador, Smith, Wheless, Sittenfeld, & Clifton, 1999; see de Lafuente & Romo, 2005, for similar results reported using single-cell recordings in monkeys).

It is worth noting here that Palva and colleagues (2005) also used MEG in order to investigate the correlation between neuronal oscillations and the conscious perception of somatosensory stimuli presented at threshold intensity. They reported that cortical broadband activity in a network comprising the somatosensory, frontal and parietal regions, was phase-locked with the subsequently perceived stimuli as early as 30–70 ms (and up to 150 ms) from stimulus onset. By contrast, stimuli that went unnoticed showed a weak phase locked activity that was confined to somatosensory regions. This data would appear to suggest an early temporal neural correlate of tactile consciousness and the involvement of a complex sensory-fronto-parietal network (perhaps related to the organization of responses toward stimulated regions of space and/or body surfaces) in the awareness of somatosensory information (though see Aukstulewicz et al., 2012, for a report suggesting that the event-related potential (ERP) responses from sensory areas that arise after we become aware of a stimulus can be explained by increased recurrent processing in the later stages of stimulus processing).

Finally, Schubert et al. (2006) tested neurologically healthy participants by using *suprathreshold* tactile stimuli, and recorded ERPs in response to stimuli that had been correctly detected and for stimuli that went undetected (consequent to the presentation of backward masking). They found that the early ERP components (P60 and N80) generated in the somatosensory cortex contralateral to the stimulated region of the body, were uncorrelated with the perception of the stimulus. By contrast, the amplitude enhancement of later ERP components (P100 and N140 in parietal and frontal areas, respectively) were only observed for consciously perceived target stimuli. Schubert et al. went on to conclude that the early activation of S1 is not sufficient to elicit conscious perception of a stimulus, which could be mediated instead by the activation of frontal and parietal areas (see also Sarri et al., 2006, for an fMRI study reporting the activation of the parietal cortex, as well as the somatosensory cortex when a patient affected by extinction became aware of tactile

contralesional information, but not on trials in which he was unaware of such information). Furthermore, they also suggested that this activation in higher-order brain areas might be related to the functioning of some kind of spatial attention mechanism.

Taken together, then, the results of those studies that have attempted to investigate the physiological substrates of tactile consciousness suggest that in-and-of-itself the activation of S1 is insufficient to elicit the awareness of a tactile stimulus. This result is consistent with the view outlined in this chapter that higher-order associative cortices, which are involved in the processing of spatial information (and which have been shown to exhibit multisensory characteristics) appear to be closely related to our awareness of tactile events.

4.10 Conclusions

The present review of the literature regarding our consciousness of tactile information has highlighted several similarities, but also a number of important differences, with respect to the results that have emerged from the more extensively studied area of visual consciousness. Specifically, while participants seem to be aware of up to three to five stimuli in vision, our tactile awareness of events is limited to 1–3 stimuli at any one time, depending on the location from which the stimuli happen to be presented (fingertips vs. the rest of the body surface; e.g., Gallace et al., 2006a; Riggs et al., 2006). Similarly, the phenomenon of visual change blindness has been demonstrated when a minimum of five stimuli are presented in the to-be-compared displays. By contrast, changes in tactile displays composed of only two to three stimuli frequently go unnoticed. Note also that while only one distractor presented between two successively presented tactile displays is sufficient to elicit change blindness, several distractors are typically required in order to induce the phenomenon in vision. Furthermore, visual distractors can impair a person's awareness of change in the tactile modality, but this does not occur when tactile distractors are presented together with visual displays composed of up to four to five stimuli (e.g., Auvray et al., 2008; though we cannot rule out the possibility that such an effect might be found when using visual displays composed of a larger number of tactile stimuli). Finally, short-term representations of tactile stimuli, as compared to visual stimuli, seem to be constrained by a storage system that has a fundamentally lower capacity (Bliss et al., 1966; cf. Coltheart, 1980).

Some years back, Gregory (1967) suggested that touch may constitute a more “primitive” sensory modality (when compared to vision and audition), and that tactile information requires only minimal processing capacity. Indeed, given that information provided by the visual system is of only “indirect” use (note that Gregory justified this argument by saying: “one cannot be attacked and eaten by an image [. . .], and neither can one feed on images”; p. 370), in order to use such information considerable computation is required by the cognitive system (i.e., optical information must be transformed into hypotheses regarding the nature of distant stimuli before organizing a response to them). By contrast, given that touch provides information of immediate value to an organism (see also George Berkeley, 1709), their information requires only a “minimal computer” (Gregory, 1967, p. 370). It is also interesting to note from the ontogenetical point of view, that that tactile modality is the first to develop and that just before the eighth week of gestation, an embryo may develop sensitivity to tactile stimulation (e.g., Bernhardt, 1987; Gottlieb, 1971; see also Humphrey, 1992). These observations would therefore appear to strengthen Gregory's claim that the visual system (as compared to the tactile system) requires a more prolonged development in order to become fully effective.

Following on from these suggestions, one might be tempted to argue that the apparent differences between consciousness in touch and vision reported in this review of the literature, might

be related to the “more primitive” nature of tactile as compared to visual information processing. However, the possibility should also be borne in mind that these differences might only be suggestive of the fact that we are much more accustomed to gathering information through the visual modality than via the sense of touch (see also Field, 2001). It would therefore be interesting to investigate tactile consciousness, by means of tasks such as change detection, numerosity judgments, and delayed report, in congenitally blind individuals for whom the tactile modality is thought to provide the main source of information regarding the external world (e.g., Millar, 1994).

It is also worth mentioning here that behavioral studies on humans and neurophysiological studies on monkeys have revealed that extensive practice in using specific parts of the body to receive tactile information (such as to perform a tactile frequency discrimination task on the fingertips) can sometimes lead to quite dramatic improvements, as measured in terms of tactile discrimination thresholds, for the particular body-part concerned (e.g., Craig & Belser, 2005; Kowalewski, Kattenstroth, Kalisch, & Dinse, 2012; Recanzone, Jenkins, Hradek, & Merzenich, 1992; see also Bach-y-Rita, 2004; Roberts & Humphreys, 2010). Early studies of tactile information processing in humans also suggested that people can be trained to perceive even large amounts of information by means of their sense of touch, just after learning a tactile codification system such as the tactile alphabet “Vibratese” (e.g., Bliss & Kotovsky, 1963; Geldard, 1960; Linvill & Bliss, 1966; von Haller Gilmer, 1961; White, 1970; see Craig, 1977; for the report of two sighted individuals who, once trained to use tactile displays, achieved a discrimination ability superior even to that of blind individuals who were highly experienced with such displays; cf. Collins, 1970; Craig, 2005; Kóbor et al., 2006).

Such results, together with the evidence provided by fMRI regarding the effect of continuous stimulation of a specific body part on the activation of the human somatosensory cortex representing that part of the body (e.g., Hodzic et al., 2004), highlight the plasticity of the cerebral networks controlling the perception and perhaps also the awareness of tactile information. It is therefore conceivable that training participants to use their bodies/fingers as a means of perceiving information, might reduce, at least in part, any possible difference between consciousness in the tactile and visual sensory modalities. Moreover, this set of observations may also strengthen suggestions that differences might be expected when tactile consciousness is investigated in sighted participants, as compared to blind individuals who are more experienced in using their sense of touch. Any such differences that happen to be observed might be related both to the reorganization of the brain in visually impaired individuals and to the effect of extensive practice with tactile stimuli/interfaces (cf. Kupers, Fumanl, de Noordhout, Gjedde, Schoenen, & Ptito, 2006, for evidence that TMS over the visual cortex can induce somatotopically organized qualia in blind participants).

The review of the literature outlined in this chapter regarding the processing of tactile information suggests that certain characteristics are peculiar to tactile consciousness, as compared to the consciousness of stimuli presented in other sensory modalities. Specifically, the awareness of tactile information seems to be inseparable from the processing of *spatial information* in the brain. Conscious tactile sensations appear to be referred to positions in external space rather than on the skin surface where the tactile receptors are actually located (e.g., Kitazawa, 2002; Wieland, 1960; Yamamoto & Kitazawa, 2001). In part, this might not be so surprising: Indeed, if one thinks of our consciousness of visual events, it is self-evident that we locate the visual percepts in external space rather than on the surface of our retina (note, however, that touch, in contrast to vision, is thought to provide both *direct* information, regarding the state of the body, and, especially during active manipulations, *distal* information regarding the external world; e.g., Martin, 1995; see Spence,

Nicholls, & Driver, 2001, for a discussion of this point). However, what is particularly unexpected and striking here is not only that we do not perceive the stimulation at the location of the receptors on the skin, but that we can consciously perceive tactile stimuli in spatial positions where our body is not physically present!

The results of the study of brain-damaged patients and neurologically normal participants reviewed in this chapter revealed that visual information effectively modulates our tactile awareness of events. Note that this observation does not necessarily suggest that visual consciousness “dominates” over tactile consciousness (see Ernst & Banks, 2002, on this point), but rather that multisensory integration might occur before access to consciousness is attained. Animal as well as human studies have revealed that such integration occurs at various different levels of neural processing including at the subcortical level in the superior colliculus (e.g., Meredith & Stein, 1983; Wallace & Stein, 1997; see also Cappe, Rouiller, & Barone 2012), the thalamus (e.g., Tyll, Budinger, & Noesselt, 2011) and the putamen (e.g., Alexander, 1987; Graziano & Gross, 1993), as well as at the cortical level in the polysensory zone (in the precentral gyrus of the monkey brain; Fogassi, Gallese, Fadiga, Luppino, Matelli, & Rizzolatti, 1996; Graziano, Hu, & Gross, 1997; Rizzolatti, Scandalora, Matelli, & Gentilucci, 1981), the ventral intraparietal area (e.g., Colby, Duhamel, & Goldberg, 1993), lateral and medial intraparietal areas (e.g., Mullette-Gillman, Cohen, & Groh, 2005), areas 7a and 7b (e.g., Graziano & Gross, 1995; see Graziano, Gross, Taylor, & Moore, 2004, for a review), the superior temporal sulcus (e.g., Beauchamp, Yasar, Frye & Ro, 2008), the lateral occipital-temporal cortex (e.g., Beauchamp, 2005) and the ventral prefrontal cortex (e.g., Romanski, 2012)

Phenomena related to multisensory integration, such as the visual capture of tactile sensation highlighted in the rubber hand illusion (see section 4.5; see also Chapter 8), or the “ventriloquist effect” occurring between vision and audition (i.e., the mislocation of an auditory signal toward the direction of a concurrently presented visual signal; see Bertelson & De Gelder, 2004, for a review; see also Caclin, Soto-Faraco, Kingstone, & Spence, 2002, for the capture of auditory sensations by tactile stimuli) have been shown to be cognitively impenetrable (e.g., Pavani et al., 2000; Radeau, 1994; Spence, Pavani, Maravita, & Holmes, 2004). This observation clearly suggests that while the consciousness of a stimulus presented in a given sensory modality can be enhanced by multisensory integration, this latter step of information processing does not necessarily enter our awareness. The latter argument therefore leads to another important question: Should consciousness (and its neurological substrates) be considered as being unisensory, multisensory, or even amodal in nature (see also Spence & Bayne, in press, for further discussion of this point)?

In an attempt to give a speculative answer to this question, we suggest here that only one sensory modality enters consciousness (or that only one unimodal system is active at a level of neural activation able to support consciousness) at a given time, but that information presented from other sensory modalities can speed up or slow down, and more generally affect (or modulate), this process as a function of their spatial and temporal characteristics. It is worth noting here that the idea of an independent and asynchronous consciousness is not completely novel, but has been proposed previously to account for the different attributes of a *visual* stimulus (such as its color, motion, shape, etc.; Bartels & Zeki, 1998; Zeki & Bartels, 1998a, b, 1999). More specifically, Zeki and Bartels (1999) proposed that that attributes of a visual stimulus processed at the same neural site are perceived at the same time, but those processed at different sites are perceived at different times. That is, visual consciousness is thought of as a modular phenomenon reflecting the modular organization of the “visual” brain.

Far from considering the whole organization of the cognitive system in terms of encapsulated modules (e.g., Fodor, 1983), we still believe that the same line of thinking can be extended to

by neurophysiological and neuropsychological data, this part of stimulus processing does not enter consciousness (e.g., Palva et al., 2005; Preißl, et al., 2001; Schubert et al., 2006; Schwartz et al., 2005; see also Lafuente & Romo, 2005). Neural activity at this level of information processing might be directly correlated with the physical intensity of the stimuli that are presented (cf. Laskov, 1995). Information is then transferred (in a “cascading” fashion between neurons with progressively larger receptive fields) to S2 where tactile information is integrated (note that some S2 neurons have bilateral receptive fields; e.g., Iwamura et al., 1994). We believe that information at this stage of processing does not necessarily enter consciousness, but may do when certain specific conditions are met (see below). Information from S2 is then analyzed in higher-order association areas in terms of task-specific spatial frames of reference. The neural information that enters these spatial representations might trigger feedback activity to S2 (represented in the figure by a dotted line; cf. Cauller, 1995). This may occur as a function of certain properties of the stimulus represented in S2 (i.e., intensity, location, salience, etc.) and on the level of activation already present in the spatial representation neurons (e.g., as a consequence of stimuli presented before or of selection processes). Such feedback from these spatial representations to S2 and the resulting synchronization of activity between these areas might constitute the neural correlates of tactile consciousness. On the basis of the evidence provided by neuroimaging studies it can be inferred that the amount of time required to complete this neural process may be in the order of 30–150 ms from stimulus onset (e.g., Palva et al., 2005). According to the neurocognitive model outlined here, whenever neural activity from S2 triggers a feedback signal from higher-order spatial representations, tactile information becomes conscious. Without the occurrence of such a trigger signal, tactile information (still represented in terms of intensity coding) can affect performance but cannot be reported consciously (this might be the case for the implicit processing of tactile stimuli in those patients suffering from neglect and/or extinction; e.g., Maravita, 1997). Note that information from other sensory modalities, when spatially congruent with tactile information, might also help to trigger such feedback (and thus facilitate neural synchronization). The latter condition may help to explain the spatial congruency effects that have been documented between different sensory modalities in speeding-up the access to consciousness of tactile information. By contrast, when spatial information is inconsistent between stimuli presented from different sensory modalities, competition arises thus potentially preventing or delaying the access to consciousness (e.g., more widely diffused and/or spatially uncorrelated neural activity might reduce the likelihood of—or increase the threshold necessary for—triggering the feedback from amodal/multisensory spatial representations to S2; cf. Gallace et al., 2008b).

Under those conditions in which spatial representations are damaged (such as in the clinical syndrome of neglect or extinction) access to consciousness of tactile, as well as visual and auditory information may be impaired or prevented, though their processing remain possible up to a certain level (e.g., Berti & Rizzolatti, 1992; Driver & Vuilleumier, 2001; Köhler & Moscovitch, 1997; Maravita, 1997; Marzi et al., 2000; Wallace, 1994). It is also worth noting that the neural network represented here, that is thought to be involved in the awareness of a given piece of tactile information, is the same one that is involved in the processing (and perhaps also selection for response) of that information (cf. Berti et al., 2005). That is, no areas other than those involved in tactile information processing are responsible for the awareness of tactile events.

It has been suggested that the cognitive processes supporting phenomenal awareness should be based on dynamic cell assembly formation rather than on explicit single-cell codes (e.g., Singer, 2001). Therefore, the conditions favoring the formation of dynamically organized assemblies in restricted regions of the brain ought to be the same as those necessary for awareness to occur. It is

possible that the organized firing of a certain number of neurons in the system responsible for the processing of tactile and spatial information (which includes the somatosensory cortex and the posterior parietal cortex) correlates with tactile awareness. This firing may also need to activate some type of short-term memory (likely involving the perirhinal cortex and the posteroventral insula; see Bonda et al., 1996) in order to maintain this information within the window of the “tactile present,” and to integrate it with information coming from other sensory modalities and/or different sources of stimulation.

The appropriate synchronization among cortical neurons may support the formation of dynamic cell assemblies and therefore provide one of the conditions necessary for the awareness of visual stimuli (Singer, 2001). Although precise neuronal synchronization has been reported within the visual (e.g., Singer, 1993; Singer, Engel, Kreiter, Munk, Neuenschwander, & Roelfsema, 1997; Singer & Gray, 1995), as well as the somatosensory cortices (e.g., Murthy & Fetz, 1992; Nicolelis, Baccala, Lin, & Chapin, 1995; Steriade, Amzica, & Contreras, 1996; see also Steinmetz, Roy, Fitzgerald, Hsiao, Johnson, & Niebur, 2000), no robust evidence for synchronization across the areas involved in the processing of information from different sensory modalities has been reported to date, perhaps strengthening the case for an unisensory account of consciousness (Spence & Bayne, *in press*). Further research, and in particular multiple single-cell recordings from different areas of the brain in animals, together with neuroimaging techniques in humans, will probably help, in the future to deliver an answer the question of whether or not consciousness has to be considered a unisensory phenomenon.

In summary, the research that has been reviewed in this chapter has highlighted that tactile consciousness may reflect a fundamentally unisensory phenomenon (in terms of its phenomenology), one that is well differentiated from the consciousness of stimuli presented in other sensory modalities. However, the information presented in other sensory modalities can affect the consciousness of events presented in the tactile modality, either by facilitating or impairing an observer’s awareness of them (likely as a function of their spatial coincidence versus spatial misalignment). As far as the temporal relationship between multisensory processing and consciousness is concerned, the available evidence would seem to suggest that multisensory integration appears to occur prior to the conscious access to information regarding tactile stimuli. On the basis of the studies reviewed here, one might conclude that spatial processing and spatial representations based on a variety of different frames of reference play a key role in the consciousness of tactile events. Similarly, the conscious perception of touch is not necessarily determined by the location of the receptors on the skin surface, but may be flexibly referred to different locations in external space. As far as the neural substrates of tactile consciousness are concerned, a large number of studies clearly demonstrate that activity in S1 does not appear to give rise to consciousness of tactile stimuli. By contrast, the neural correlates of tactile consciousness might be related to a circuit that comprises higher-order processing areas such as S2, the posterior parietal cortex, the temporoparietal junction, and the premotor cortex. Such a circuit might be involved in the planning and execution of movements toward particular regions of space and/or of the body surface.

In conclusion, in the present chapter, we have seen how tactile consciousness is an important, but yet still largely under-investigated empirical phenomenon, one that deserves more serious attention from the wider scientific research community. Specifically, we have illustrated that many of the questions regarding the nature of tactile consciousness (such as those addressing its spatial and temporal limitations), and its possible distinctiveness from consciousness in other sensory modalities still remain unanswered. Nevertheless, the present review has highlighted the inseparability of the study of tactile consciousness from the study of spatial and multisensory processing

in order to understand the cognitive and neurological substrates of our awareness of tactile events. Having reviewed the evidence on tactile awareness/consciousness, we will, in Chapter 5, go on to look at those neurocognitive systems responsible for storing and maintaining information regarding the tactile qualities of the stimuli that occurs on our body surface.

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Chapter 5

A memory for touch

5.1 Introduction

Memories are what make the external world “ours.” They determine who you are, where you are going, what you like, and why you are doing a certain thing at a specific moment in time. They influence the large majority, if not all, of the decisions you make in your life, be it what food to choose at a restaurant or what kind of job position to apply for. As effectively summarized by the following quote, without memories, we would be imprisoned within an eternal present (such as in those unfortunate individuals with damage to their memory systems; e.g., Corkin, 1984): “Memory assures us of our continuity through time; without it we seem to become nothing but fragments” (Appleyard, 2012, p. 57). It is not surprisingly, then, that researchers have always been very interested in this topic.

Among all of our memory systems, tactile memories certainly play a very important role in many of our everyday activities, even if we mostly tend not to be aware of it. Think, for example, of the physician who touches a patient’s lymph gland and immediately and nearly automatically recognizes it to be swollen. He/she can only do this because he/she can remember the feel of a normal gland. The human brain needs a complex tactile memory system in order to execute the daily activities associated with storing and retrieving tactile information (and thus facilitating the accurate recognition of objects that have previously been explored haptically). The study of tactile memory can help us to understand how this complex system works and which areas of the human brain are responsible for the maintenance of tactile memories. Just as seen for other aspects of our behavior, a large body of empirical research has investigated the neural mechanisms and limitations associated with visual (and to a lesser extent auditory) memory, while less attention has been directed to the topic of tactile and haptic memory (see Figure 5.1; Atkinson & Shiffrin, 1968; Baddeley, 2007; Coltheart, 1980; Cowan, 1984, 1995; Darwin, Turvey, & Crowder, 1972; Ebbinghaus, 1885; Neisser, 1967; Phillips & Baddeley, 1971; Treisman & Roston, 1972; see also Engen, 1987; Parrao, Chana, Venegas, Behrens, & Aylwin, 2012; Jönsson, Møller, & Olsson, 2011; Zucco & Bollini, 2011, for research on the topic of olfactory memory).

Research conducted over the last decade or so has revealed that the cognitive limitations affecting the processing of tactile stimuli/information appear to be more severe than those affecting the processing of visual and auditory stimuli (see Gallace et al., 2006a, 2007b, 2008a; see also Chapter 4). Consequently, one might legitimately query whether or not the same constraints that have been shown by cognitive scientists to affect the storage and retrieval of visual and auditory information also affect people’s memory for tactile perceptions as well.

Given that the particular conditions under which stimuli are presented (e.g., serial vs. parallel presentation, active exploration vs. passive stimulation, etc.) affect the amount of information that is available and how that information is processed and remembered (e.g., Millar, 1978a, 1999, 2006), and given that touch differs from both vision and audition in so many important ways (see Chapters 3 and 4), one should perhaps also expect there to be a number of important differences between our tactile memories and our memories for stimuli that have been experienced

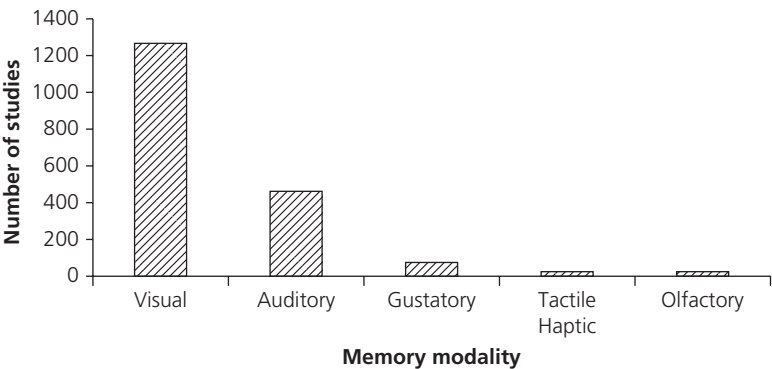


Fig. 5.1 Bar chart summarizing the number of studies in which the topic of visual, auditory, gustatory, olfactory, or tactile/haptic memory have been reported in the title from 1806 to 2010. Source Scopus (research date: October 10, 2012). The graph illustrates the fact that Katz’s (1925) early complaint concerning the number of studies on vision outnumbering those on touch still holds true more than eight decades later.

via one of the other senses. We therefore believe that issues surrounding the topic of tactile memory represent an important, if at present relatively understudied, topic for empirical research (cf. MacDonald, 2007).

At the outset, it is perhaps worth noting that when talking about the memory for touch an important distinction should be drawn between people’s memory for the microgeometric properties of stimuli (for example, regarding their fine textural features), their memory for the macrogeometric properties of the stimuli (such as rough textural information, as well as information about an object’s shape and size etc.; see Table 5.1), and their memory for the spatial qualities of

Table 5.1 Differences between the macrogeometric, microgeometric, and spatial aspects of tactile perception.

	Microgeometric	Macrogeometric	Spatial
Aspect of the stimuli coded	Texture, roughness, & spatial density of surfaces	Shape, size, & structure of objects	Location of stimuli
Stimuli that can be coded	Objects small enough to fall within a single region of skin	Objects that can be enveloped in the hands or limbs	Vibration or pressure of stimuli actively manipulated or passively presented on the skin surface
Receptors involved	Mechanoreceptors located in the skin	Integration of information from mechanoreceptors & kinesthetic receptors in regions of the skin that are not necessarily somatotopically continuous (e.g., the fingers of the two hands)	Higher order integration of information from mechanoreceptors & proprioceptive receptors located in the skin
Neural substrates	Parietal operculum	Anterior part of parietal lobules	Right superior parietal lobule, temporoparietal junction

tactile stimuli (i.e., their memory for the location(s) on the body surface, or in space, where the stimulation happened to occur), each being processed in distinct regions of the human brain (e.g., O'Sullivan, Roland, & Kawashima, 1994; Roland, 1987; Roland, O'Sullivan, & Kawashima, 1998).

The difference that has been put forward in the tactile literature between the microgeometric and macrogeometric properties of stimuli relates to the observation that both 3D objects and surfaces represent important constituents of the tactile (as well as the visual) world, and that each of them can be characterized by specific qualities (see Klatzky & Lederman, 1993, 2002). Specifically, many surfaces contain small irregularities and/or elements that cannot be individuated, thus giving rise to the phenomenological impression of roughness, or texture (i.e., the microgeometric properties of a stimulus). The activation of the rapidly adapting mechanoreceptors (resulting from the displacement of the skin) located on our fingertips contribute to the perception of the texture of a surface when we explore it haptically (i.e., with our hands; Hsiao, Johnson, & Twombly, 1993; see Mountcastle, 2005, for a review). By contrast, the length, area, curvature, and shape of a stimulus all constitute macrogeometric surface properties. In the latter case, the integration of slowly adapting mechanoreceptors in the skin (that respond when the skin or touch-responsive hairs are depressed) and kinesthetic/proprioceptive receptors (providing information regarding the positions of our limbs and joints) contributes to the perception of the shape of any object held in the hands (see Sakata & Iwamura, 1978, for evidence concerning the convergence of cutaneous and proprioceptive inputs in neurons located in the posterior parietal cortex of the monkey brain; see also Voisin, Lamarre, & Chapman, 2002).

Although the various forms of tactile memory just mentioned are not necessarily independent (e.g., in order to correctly recognize a complex scene by means of touch alone, both the macrogeometric and microgeometric properties of the stimulus, together with the spatial position of its elements, typically need to be processed), this chapter will primarily focus on reviewing the literature concerning people's memory for the macrogeometric and spatial properties of stimuli presented tactually/haptically. This choice is justified by the fact that very little research has so far attempted to investigate the properties of our tactile memory for the microgeometric stimulus properties (cf. Spence & Gallace, 2008).

Another important issue to be considered when discussing tactile information processing regards the distinction between active (haptic) and passive touch (e.g., Gibson, 1962; Loomis & Lederman, 1986). Given the multisensory nature of much (if not most) of our tactile perception (see Chapters 2 and 4), this chapter will question whether tactile memories (or at least a proportion of them) must also, of necessity, typically derive from multisensory information processing occurring in the brain (and hence whether they are based on multisensory neural representations).

In the literature review presented here, we briefly summarize the extant cognitive and neuroscientific literatures that have attempted to examine people's memory for information presented via the skin. We will demonstrate how the study of tactile/haptic memory has provided important insights into the neural and cognitive mechanisms underlying the way in which we store and code information regarding the objects with which we interact, or that impinge on the surface of our body. The study of tactile memory (note that the term "tactile memory" will be used in this chapter (and in the rest of the book) as a shorthand to describe those memories that result from both active and passive stimulation) should also help to shed some light upon the mechanisms underlying the "perception" of tactile/haptic information as well, given that our perception depends, at least in part, on previous experiences and on the information that has already been stored and processed in the brain (see Norman, 1968). Following this line of reasoning, we will

put forward the argument that the very same neural networks that are involved in the initial sensory processing of tactile information are also involved in the storage of tactile stimuli in the brain (such as has been demonstrated for visual memories; e.g., McClelland, McNaughton, & O'Reilly, 1995; Rösler & Heil, 2003).

Finally, this chapter will also highlight the fact that certain neurocognitive systems thought to process “amodal” stimulus qualities (i.e., that are likely shared between different sensory modalities), such as those involved in the computation of the spatial aspects of stimuli, might play a very important role in the storage of tactile information in the brain. After having reviewed those studies that have presented tactile stimuli passively to the participants’ skin in order to investigate those processing systems that are responsible for the sensory and central forms of memory, research that has involved the haptic exploration of the stimuli by participants will be discussed. The representation of haptically explored stimuli and questions concerning the nature (amodal/multisensory or unimodal) of these representations are addressed in detail in section 5.3 while the problem regarding whether or not tactile representations can be translated into visual representations is discussed in section 5.4 (cf. Jacomuzzi, Kobau, & Bruno, 2003; Molyneaux, 1688; Morgan, 1977; Paterson, 2006; see also Held et al., 2011). There, we review those studies that have investigated the role of mental/visual imagery in the storage of haptic information. Given that the “visual” representation of haptic material is thought to be absent in congenitally blind individuals, this chapter also deals with the storage of tactile stimuli by this group (by comparing the performance of congenitally blind individuals with that of individuals who lost their sight in later life and with that of sighted individuals). The possibility that tactile stimuli are coded solely by means of a verbal code is tackled next by reviewing the literature on those studies of infants who have not yet developed the ability to encode stimuli verbally. Section 5.7 investigates whether the difference between implicit and explicit forms of memories reported previously in studies of vision are also present in touch. The affirmative answer to this question once again leads to further discussion of whether or not the commonality of phenomena reported between vision and touch are related to shared memory representations in the human brain. In the final section of this chapter, we summarize those studies that have investigated the neural correlates of tactile memory. We will make the argument that the convergence of evidence from the various different domains of research summarized in this chapter strengthens the claim that the processing and storage of tactile stimuli cannot always be separated from the processing of other kinds of information (and, in particular, information regarding the spatial attributes of the stimuli) that is not purely tactile in nature (e.g., Gallace & Spence, 2008a). The picture of tactile memory that emerges from the review presented in this chapter, then, is one that depicts a complex neurocognitive system in which different unimodal units interact at many different levels of information processing with multisensory/amodal processing components in order to store and represent the tactile stimuli impinging upon our skin.

5.2 Peripheral and central tactile memory: An analogy with visual memory?

In this section, we review the literature that has addressed the distinction between peripheral and central forms of tactile memories following a classification that has been defined by the extant literature on visual memory (e.g., Gilson & Baddeley, 1969). In most of the studies presented here, tasks were used that involved passive tactile stimulation and the processing of the spatial attributes of the stimuli concerned. In this section, we attempt to show that, on the basis of the studies that have been published to date, the extent to which the storage of tactile information that takes

place at the level of peripheral memory systems involves multisensory (e.g., spatial) or rather purely tactile (i.e., unisensory) neural representations still remains unclear.

Previous behavioral studies of *visual* memory have highlighted the existence of a number of different memory systems, each with a seemingly distinct and highly specific function. Researchers have, for example, made distinctions between long- and short-term forms of memory (e.g., Atkinson & Shiffrin, 1968), between implicit and explicit memory (e.g., Brooks & Baddeley, 1976; Schacter, 1987), and between semantic and procedural memory (e.g., Anderson, 1986), to cite just three of the principal categorizations that have been put forward to date. Moreover, within the short-term memory system, a peripheral/sensory (modality-specific) memory system of high capacity but short duration (named “iconic memory” in the visual modality; e.g., Sperling, 1960; and “echoic memory” in the auditory modality; e.g., Cowan, 1984; see Coltheart, 1980, for a review) has been differentiated from a more central form of memory (called “working memory”) whose operation can be deleteriously affected by any other information processing that a person may happen to be undertaking at the same time (e.g., Gilson & Baddeley, 1969; see also Bliss & Hämäläinen, 2005; Bonda, Petrides, & Evans, 1996; Harris, Harris, & Diamond, 2001; Mahrer & Miles, 2002; Ricciardi, Bonino, Gentili, Sani, Pietrini, & Vecchi, 2006; see Figure 5.2). Here it is worth noting that while it has been argued that sensory memory may be capable of retaining information very accurately (although very briefly) and the sensations recalled by this system appear to be phenomenologically similar to the original stimulation (e.g., like an “echo” that retains the quality of the original sound), the experience of recollecting by means of the other memory systems appears to be better differentiated from the original perceptual experience itself.

5.2.1 People’s memory for the location of touch

Although it seems plausible that the same distinctions also apply to information presented via the skin, very little empirical research has actually been dedicated to investigating this important (but rather difficult to study) topic. In Chapter 4, we mentioned what was perhaps the first study to have investigated the topic of tactile memory for location directly. Specifically, we saw that Bliss et al. (1966) studied the ability of participants to report the locations from which multiple tactile stimuli (presented simultaneously to the fingertips of both hands) had been presented. They showed that when the participants had to report the stimuli presented to all eight fingers (i.e., the whole report condition), they were only able to correctly report about 3.6 stimuli (out of 12) but when a partial report procedure was used instead, the participants were able to report 4.6 stimuli successfully. Note, though, that although significant, this represents a much more modest improvement in people’s performance than that seen in visual studies, where up to 12 more letters can be reported on when the partial (rather than whole) report procedure is used. Bliss et al. took the difference between the results obtained using the partial versus whole report procedures to suggest the presence of a “sensory” form of memory for passively presented tactile stimuli, one that had a high capacity but short duration (i.e., a memory system that suffered from rapid decay within just a few seconds of stimulus presentation). That is, a form of tactile memory equivalent to the iconic memory investigated in vision (e.g., Coltheart, 1980; Sperling, 1960; see Table 5.2 for a comparison between people’s performance in partial and full report memory tasks).

The presence of a rapidly decaying memory system that may be used to help remember the location from which tactile stimuli have been presented on the skin has also been investigated by Gallace, Tan, Haggard, and Spence (2008b). In one experimental block, the participants in this study had to report the total number of stimuli presented in a tactile display composed of up to

Table 5.2 Number of stimuli that can generally be reported by participants in a full and partial report task, as a function of the sensory modality of presentation. Note that the number of stimuli reported using the partial report procedure provides an estimate of the capacity of the sensory memory system (e.g., Cowan, 1984; Gallace et al., 2008a; Sperling, 1968).

Visual		Auditory		Tactile	
Full	Partial	Full	Partial	Full	Partial
2–3	12–15	2–3	5	3	5

six stimuli delivered simultaneously across their bodies. In a different block of the experiment, they had to detect whether or not a tactile stimulus had been presented in a position signaled by a visual probe given at a variable delay (of between 20 and 5000 ms) after the presentation of the tactile stimuli themselves. Gallace et al. ’s results revealed that the participants were only able to report three of the stimuli correctly when they were asked to indicate the total number of locations that had been stimulated.

Interestingly, however, when the participants were required to report only a subset of the tactile locations that had been stimulated, the results suggested that they were able to access information regarding the positions of up to five of the stimuli. This result confirmed the fact that short-lasting tactile representations can be accessed using partial report procedures, similar to those used previously to study iconic memory in vision. Moreover, Gallace et al. (2008b) also demonstrated that the duration of these representations (or, at least the time in which they can be accessed consciously) depends upon the number of stimuli presented in the display; that is, the more tactile stimuli that were presented, the faster the mental representations of the display appeared to decay.

Although the results of Gallace et al. ’s (2008b) study, just as was the case for earlier studies of visual sensory memory (e.g., Sperling, 1960), appear to show the presence of a rapidly decaying form of sensory storage concerning the site of tactile stimulation, it is still somewhat unclear whether the nature of this representation is actually purely tactile or, at least to a certain extent, spatial in nature. Indeed, it has been proposed that the decay of iconic visual representations involves the loss of “spatial” information about the items, rather than a loss of information concerning the identity of those items (e.g., Mewhort, Campbell, Marchetti, & Cambell, 1981; see also Mewhort & Campbell, 1978; Mewhort & Leppmann, 1985; Mewhort, Marchetti, Gurnsey, & Campbell, 1984; Townsend, 1973). The role of spatial information might be even more relevant in the case of the tactile modality, given the close link that has been proposed between the awareness of tactile information and the spatial processing of that information (see Gallace & Spence, 2008a, for a review). In the future, it would be interesting to study the possible presence of spatial biases on the memory for the location of tactile stimuli as a function of different frames of reference (somatotopic or space-based; see Chapters 2 and 3). Given that different aspects of tactile information processing (such as the perceived location and distance between a pair of concurrently presented stimuli; Cholewiak, 1999; Fuchs & Brown, 1984; Green, 1982) varies with the location across the body surface where the stimuli are delivered, one might also expect an effect of spatial factors on the storage and recollection of passively presented tactile stimuli.

Gilson and Baddeley (1969) used a somewhat different procedure in order to investigate the ability of people to report (in particular, to point to) the position of a tactile stimulus presented on their forearms after a delay that varied between 1 second and 1 minute. In one block of trials, the participants only had to remember the position of the tactile stimuli. In the other block of trials,

they had to try and memorize the position from which the tactile stimuli had been presented, while at the same time trying to perform a task designed to interfere with any verbal rehearsal strategy that the participants might have been using. In particular, the secondary task consisted of participants having to count backwards at their own pace in threes, from an initial three-digit number provided by the experimenter as she touched the participant's arm throughout the retention interval. In both conditions of stimulus presentation, the participants were explicitly instructed not to look at their arms in order to rule out the possibility that the position of the stimulus on the body was simply coded and stored visually rather than tactually. (It is, however, worth noting here that this procedure does not actually impair people's ability to use visual imagery or visual codes in order to store the location of the stimuli on their skin.)

The performance of Gilson and Baddeley's (1969) participants in the primary tactile localization task (measured in terms of the spatial deviation of participants' pointing responses from the position that had actually been stimulated), was equivalent in the two experimental conditions, at least for retention intervals of up to 10 seconds. However, once the retention interval exceeded 10 seconds, performance in the dual-task condition (requiring the execution of the secondary task) was far worse than that observed in the single task condition. On the basis of these results, Gilson and Baddeley went on to conclude that participants' performance during the first 10 seconds following the presentation of the stimuli had been related to the functioning of a more sensory form of tactile memory, whereas that observed during the longer retention intervals was related to the operation of a more central memory system instead (though see Miles & Borthwick, 1996; Sullivan & Turvey, 1972).

Gilson and Baddeley's (1969) original study was subsequently replicated by Miles and Borthwick (1996). They also investigated whether the nature of a concurrently presented task affected their participants' ability to recall tactile information. In particular, they compared the effect of articulatory suppression, tactile interference, and both applied in combination on the reported position of a tactile stimulus previously presented on the participant's forearm. In contrast to Gilson and Baddeley's results, Miles and Borthwick reported that the recall accuracy of participants in the pointing task deteriorated as the delay increased, regardless of the particular experimental condition (see also Sullivan & Turvey, 1972). Miles and Borthwick also reported that the accuracy with which their participants could recall the location from which the stimulus had been presented was equally impaired in all three experimental manipulations, which they interpreted as providing support for the existence of a rapidly decaying tactile memory trace, one that did not appear to be aided by verbal rehearsal of the stimulated location. Moreover, Miles and Borthwick also suggested that the two interfering tasks acted upon different cognitive mechanisms. That is, while tactile interference reduced the discriminability of the target location, articulatory suppression resulted in the depletion of central processing resources concerned with the memorization of the original location of the tactile stimulus instead.

In both of the studies of tactile STM that have been reported so far (Gilson & Baddeley, 1969; Miles & Borthwick, 1996) it is difficult to exclude completely the possibility that the position of the stimuli presented on the participant's skin was not also coded (or retained) by means of visual imagery (see also section 5.5 on the role played by visual imagery in tactile memory). That is, the rapid decay of the tactile memory trace might actually have been due to the rapid decay of the corresponding visual mental image concerning the location on the skin (or in space) that had been touched. The question of what role visual imagery plays in the decay of tactile sensory memory certainly needs to be addressed in future research. Ideally, the participants in any such research in this area should perform tactile memory tasks while their visual imagery "system" is engaged in some other concurrent task (e.g., see Beech, 1984). More specifically, both non-spatial visual

and visuospatial interpolation tasks would be needed in order to determine whether it is visual imagery per se that impairs tactile memory, or whether instead it is solely the spatial processing required by visual imagery that determines the detrimental effect (e.g., Millar & Al-Attar, 2005). This would then enable the researchers concerned to isolate any effects related to the rapid decay of the tactile sensory trace from those attributable to the deployment of visual imagery.

Studies of “tactile masking” also suggest the presence of short-term forms of sensory memory in touch: Masking can be defined operationally as a reduced ability to discriminate a test stimulus upon the presentation of another stimulus (e.g., Cholewiak, 1999; Craig, 1976, 1977; Gilson, 1968; Kirman, 1973; Sherrick, 1964; von Békésy, 1967, 1959; see also Parmentier, Ljungberg, Elsley, & Lindkvist, 2011). The masking effect becomes relevant to the topic of tactile memory given that this phenomenon can be elicited not only when the target and the masking stimulus are presented concurrently, but also when they are presented sequentially (with a delay of up to 70 ms between them; see Laskin & Spencer, 1979). Tactile masking effects decrease as the interval between the target and the masking stimulus increases (e.g., Laskin & Spencer, 1979), thus suggesting that the masking stimulus interferes with a rapidly decaying neural trace associated with the target stimulus.

However, before drawing any firm conclusions regarding the role of masking in highlighting the presence of a sensory form of tactile memory, one also needs to consider the fact that crossmodal masking has, on occasion, been reported between stimuli presented in different sensory modalities (i.e., between touch and audition; see Gescheider & Niblette, 1967; though see also Brown, Galloway, & Gildersleeve, 1965). The presence of such a crossmodal phenomenon would seem to compromise the view that the masking effect is solely related to a sensory form of tactile memory. It is, however, worth mentioning here that certain studies have shown that crossmodal interactions can occur at the level of “unisensory” processing areas in the brain (e.g., Allman & Meredith, 2007; Ghazanfar & Schroeder, 2006). Such observations might then undermine the view that the presence of crossmodal masking effects necessarily implicate the involvement of higher-level processing areas in the representation of tactile information, but not the view that sensory information can be stored by means of crossmodal networks (connecting different unisensory areas). In the years to come, it will be important for researchers to address the phenomenon of crossmodal masking and its relation to different forms of tactile memory in more detail (given that the only published research on this important topic is now many years old).

Evidence in support of the existence of a modality-specific form of tactile STM comes from a study reported by Watkins and Watkins (1974). The participants in this experiment had to try and recall the serial order in which the fingers of their two hands had been touched. The researchers reported that task performance was disrupted if the experimenter stroked two of the participant’s fingers at the end of a series of to-be-remembered stimuli (a phenomenon known as the “suffix effect,” demonstrated previously in both the auditory and visual modalities; e.g., Baddeley & Hull, 1979; Greene, 1987). This result was taken to support the existence of a modality-specific form of tactile short-term memory, one that is affected by the presentation of irrelevant information in the same sensory modality as the to-be-remembered stimuli (see also Manning, 1978). However, it should be pointed out here that, in principle, finger locations can simply be coded spatially or even visually with reference to a body-centered frame of reference. Therefore, it would seem difficult to argue unequivocally that Watkins and Watkins’ results provide clear evidence in support of the existence of a modality-specific peripheral form of memory for the short-term storage of tactile information (see also Millar, 1999, for a similarly critical conclusion).

As far as the presence of modality-specific forms of sensory memory in touch are concerned, by using a variant of the suffix task, Manning (1978) was able to demonstrate that the serial recall of tactile information is impaired by the presentation of a visual (spatial) task interpolated between

the presentation and recall of the tactile stimuli. Even more interestingly, the interpolated task not only affected the report of the last stimuli presented in the sequence (supporting a sensory memory account of the results) but also that of earlier stimuli in the sequence. That is, no recency effect was reported by Manning (see Watkins & Watkins, 1974, for a similar result). This result would appear to suggest that the suffix effect might be better explained in terms of a “general distraction” effect rather than in terms of the prevention of access to a rapidly decaying sensory representation of the stimuli (note that this contrasts with Manning’s preferred interpretation of the data). Once again, the problem of whether or not the representation of tactile information also requires neural systems that are not devoted solely to the processing of tactile stimuli (such as those involved in sustaining visual and spatial representations) has yet to be resolved.

Different interpolated tasks have also been used to investigate the short-term representation of objects and their spatial orientation (e.g., Gentaz & Hatwell, 1996, 1999; Hatwell et al., 2003; Heller, Calcaterra, Green, & Brown, 1999). Participants in a study by Gentaz and Hatwell (1999) scanned a rod haptically and then tried to reproduce its orientation after a delay of either 5 or 30 seconds. One of two possible interpolated tasks (one verbal and the other haptic) was presented between the encoding and recollection phases of the experiment. The results revealed that both tasks interfered with the storage of information concerning the orientation of the rod, thus leading to a deterioration of participants’ performance. Interestingly, though, no difference in performance between the two interpolated tasks and the two delay intervals was observed, thus arguing for the involvement of a higher/central form of memory. Furthermore, in a second experiment, Gentaz and Hatwell added gravitational (i.e., proprioceptive) cues during the encoding block of the experiment (by preventing participants from resting their arm during their exploration of the rod). In this condition, participants’ performance was unaffected by the two interpolated tasks. On the basis of their results, the authors concluded that the mode of coding based on a geocentric frame of reference (i.e., based on the direction of gravity and used when gravitational cues are present and different from the “movement coding” used when gravitational cues are not available) does not put excessive demands on attentional resources to process orientations in STM. That is, different modes of memory coding (e.g., based on different frames of reference) may differ in terms of the attentional resources that they require in order to process and maintain information regarding the orientation of objects (cf. Dalton, Lavie, & Spence, 2009, for later research detailing the relationship between tactile working memory and selective attention).

The duration of tactile STM has also been studied as a function of the sensitivity of different skin sites to tactile stimulation (e.g., Murray, Ward, & Hockley, 1975). It has been known for many years that tactile sensitivity varies as a function of the particular skin site stimulated (people are, for example, more sensitive to tactile stimuli on their fingertips and on their lips than on their back or forearms; e.g., Weinstein, 1968; see also Gemperle et al., 2003). The participants in Murray et al.’s study had to try and determine whether two locations (out of 12 possible skin sites) stimulated one after the other, at a variable temporal interval, were the same or not. The authors calculated a “memory threshold,” defined as the maximum distance between two stimuli that would still yield a “same” response by participants following the presentation of four identical pairs of stimuli (the larger this distance, the worse a participant’s ability to retain the exact information regarding the position stimulated).

Murray et al.’s (1975) results revealed that the lower the sensitivity of the skin site stimulated (as measured in terms of the two-point discrimination threshold; i.e., the smallest spacing between two locations on the body allowing for two stimuli to be perceived as distinct; see Weinstein 1968), the higher the degree of forgetting the previously stimulated body location (i.e., the memory

threshold was higher). This result would appear to suggest that the sensory processing of tactile information and tactile memory are strongly linked (see also section 5.7 on the neural correlates of tactile memory for confirmation of this observation using neuroimaging; e.g., Ricciardi et al., 2006). However, one might wonder here whether the same results (and conclusions) would have been observed had non-spatial tasks been utilized instead.

Finally, if one's aim is to compare the span of tactile short-term memory with the span for memories of stimuli presented in the other sensory modalities, it is worth mentioning that different researchers have come to somewhat different conclusions with regard to this topic. In particular, while Millar (1975b) has argued for a very limited memory span for serially presented tactile stimuli, Heller (1989a) claimed that the span under these conditions of stimulus presentation is similar in touch and vision. Clearly, the former claim would imply separate representations subserving the memorization of visual and tactile stimuli, while the latter claim is more compatible with the view that shared representations are involved in the storage of both kinds of material. One might, however, think that the specific requirements of the task may result in differences in the resulting memory span. For example, using visual and tactile stimuli that can be coded verbally might result in a similar span. This might be due to the fact that after an initial period of modality-specific information processing, the same representation can be used for both stimuli. As confirmation of this suggestion, it is worth noting that Millar (1999, p. 753) also claimed that "there seems to be no reason why memory spans for tactual patterns should be any worse than for the same patterns in vision, if the tactual patterns are coded spatially as global shapes." That is, when the experimenter can be certain that the same (possibly spatial) code is used by participants in order to perform the task then no differences should be expected between visual and tactile forms of memory. By contrast, when the coding strategies are ambiguous, stimuli presented in a given sensory modality might be more easily coded in a certain way than those stimuli presented to another sensory modality, resulting in possible differences in the measured memory span.

Taken together, the results reported in this section would therefore appear to support the view that, just as is the case for vision, there are several different memory systems that enable people to remember tactile sensations: At least one of which is more peripheral and modality-specific (and closely linked to the systems initially used to process incoming tactile sensations), while the other is more central (and can be affected by other forms of processing; see also Sauls & Cowan, 2007). The operation of these two systems conjointly constrains people's ability to retain information regarding the location from which tactile stimuli have been passively presented to their body surface. However, the presence in the literature of inconsistent results (e.g., compare the results of Gilson & Baddeley, 1969; Miles & Borthwick, 1996; and Sullivan & Turvey, 1972), together with the largely neglected investigation of the role played by visual and spatial information in the recall of the location from which tactile stimuli have been presented, means that further investigation will be needed in order to arrive to a clearer understanding of the neural mechanisms responsible for the short-term storage of information concerning tactile location.

5.3 Tactile representations: Are they really unisensory?

This section reviews those studies that have investigated the representations of tactile information regarding objects, bodies, and faces. The majority of the studies presented in this section involved people haptically exploring stimuli (as compared to the passive stimulation used in the majority of the studies reviewed in the preceding section). The results of the research reviewed here demonstrate that although people can easily use their tactile memory representations in order to recognize

stimuli that have been presented previously, the nature of these representations is still unclear. In particular, evidence from both behavioral and neuroimaging studies suggests that the networks responsible for the maintenance of these tactile representations might, at least in part, be shared between different sensory modalities.

5.3.1 Memory for objects that have been explored haptically

Relatively few studies have attempted to address the characteristics and functioning of our memory for manipulated (or haptically perceived) objects (as compared to the large number of studies that have addressed people's memory for visually presented objects; or those that have investigated visuotactile correspondences in object recognition: e.g., Amedi et al., 2002, 2005). Many of the early studies in this area (especially those conducted during the 1960s and 1970s) addressed the processing of geometric stimulus properties, particularly shape and size, by the haptic and visual systems (see Walk & Pick, 1981, for an extensive early review). Such studies, in which either 2- or 3D forms that were not particularly meaningful were used, focused primarily on the search for any differences between the ability of participants to recognize stimuli presented to their various senses. Almost without exception, the results of this research always revealed very poor haptic performance when compared to the other modalities (in particular, vision). Note, however, that in most of this early research, the duration of stimulus-presentation was often equated across the various modalities, thus resulting in a large disadvantage for the haptic modality where long-lasting serial (in addition to parallel) scanning procedures (of stimulus exploration) are typically needed (e.g., Knecht, Kunesch, & Schnitzler, 1996).

Other researchers have investigated the ability of both the sighted and visually impaired to recognize common objects when presented in the form of raised line drawings (e.g., Heller, Calcaterra, Burson, & Tyler, 1996; Lederman, Klatzky, Chataway, & Summers, 1990; Magee & Kennedy, 1980). The results of these studies have generally revealed that the accuracy and latency of participants' responses in this kind of task vary significantly between individuals (both within and between the different experimental groups) and as a function of the specific conditions of stimulus presentation that have been used. It is important to note here that changing certain tactile stimulus parameters (such as the size of an object) can have a dramatic effect on the rate at which they can be explored haptically, and hence, indirectly, on the specific memory demands presented by the task (i.e., more time is required to integrate the different aspects of an object into a complete representation as its size increases; e.g., see Berla, 1982). Note also that changing the orientation (across the three principal spatial axes) in which the stimuli are presented for encoding and in which they are presented for subsequent recognition has been shown to deleteriously affect people's performance in unisensory object recognition tasks (e.g., Lacey, Peters, & Sathian, 2007; Srinivas, Greene, & Easton, 1997).

One of the most important results to have emerged from those studies that have used raised line drawings or maps regards the role of spatial factors in the storage and representation of tactile information. In particular, Millar and Al-Attar (2004) provided different kinds of spatial cues while their participants had to memorize haptically presented raised line maps. They reported that disrupting any body-centered reference to the locations on the map (by changing the orientation of the map with respect to the body between the encoding and test phases of the experiment) increased the number of recall errors made by participants. By contrast, adding external reference cues, by asking participants to use a surrounding frame of reference, when body-centered reference was disrupted (again by means of a change in the orientation of the map) resulted in performance returning to the same level of accuracy as that found in the "no rotation" (baseline) condition. On the basis of their

results, Millar and Al-Attar went on to conclude that external and body-centered reference cues may have independent and additive effects on the representation of haptic information. That is, spatial factors (as mediated by different frames of reference) seem to play a particularly important role in the storage of raised line stimuli (see also Millar & Al-Attar, 2003).

Despite the relatively poor performance obtained in tactile recognition tasks when nonsense shapes are used, researchers have also reported that participants can reach levels of accuracy that are comparable to those obtained following the presentation of visual stimulus in those studies where more ecologically valid stimuli, such as 3D objects/shapes, or even real faces, are used (e.g., Kilgour & Lederman, 2002; Kiphart, Auday, & Cross, 1988; Klatzky, Lederman, & Metzger, 1985). For example, the blindfolded participants in a study reported by Klatzky et al. had to try to haptically identify 100 randomly presented 3D objects (comprising stimuli such as a book, carrot, egg, hammer, button, candle, etc.). Participants' performance in this task was surprisingly good (averaging around 96% correct). What is more, performance improved still further (up to an average of 99% correct) when false starts (i.e., starting with an incorrect response and then providing the correct one), superordinate category name (e.g., "vegetable" for carrot), or related categorical responses were also counted as correct. These results therefore demonstrate that the ability of people to remember common objects explored haptically is really rather good. This would seem to suggest that, at least under specific conditions of stimulus presentation, the tactile modality is a reliable (or "expert"; see Klatzky et al., 1985) system for the processing and storage of haptically explored stimuli.

Here, it is relevant to point out that Krantz (1972) has proposed that there are five qualities of tactile stimuli that influence people's haptic object identification abilities: The amount of exertion needed to explore the object, the roughness, the size, the temperature, and the sharpness of the object. While most of these are present when inspecting 3D objects, none of them can be correctly represented in 2D displays. The results reported in this section therefore suggest that people's retention of haptically explored stimuli seems to be strictly related to the nature of the material presented and to the time available for stimulus encoding (i.e., the amount of time provided to the participants to haptically scan the stimuli). Specifically, optimal performance is obtained when people are allowed to scan 3D everyday objects in their own time, while impaired performance is typically obtained with the brief presentation of bidimensional raised lines stimuli. This observation supports two important conclusions: (1) The integration of movement and tactile information plays an important role in people's memory of haptically explored stimuli; (2) The recognition of familiar objects might involve completely different systems (or kinds of processing) as compared to the recognition of symbolic representations of objects (and perhaps even the mediation of visual memory systems).

An important question here regarding people's memory for tactile stimuli relates to the nature of the representations that are stored in the human brain. That is, do our memory systems store multisensory or rather multiple unisensory memory representations of objects (e.g., Johnson, Paivio, & Clark, 1989; see Lacey, Campbell, & Sathian, 2007; Lacey, & Sathian, 2011, for discussions of this topic). As we have seen throughout this volume, researchers are now more interested than ever before in trying to understand how different sensory modalities interact rather than to see how each sense works in isolation (see Bremner et al., 2012; Calvert et al., 2004), and there is no reason why the storage and retrieval of information should not also be subject to this important trend. Given that the majority of events in the world are "multisensory" in nature, investigating memory abilities (and constraints) under conditions of multisensory stimulus presentation obviously constitutes a more ecologically valid approach than focusing on only a single sensory modality at a time.

Easton, Srinivas, and Greene (1997) reported a study in which their participants had to read ten words that were presented visually and ten words presented haptically. After performing a distractor task for 5 minutes, the participants were then presented with 30 three letter word stems (including the 20 items studied previously, and ten previously unstudied, i.e., novel, items). The participants had to complete the three-letter word stems, after either looking at them or else after feeling them, with the first word (longer than three letters) that came to mind. Easton et al. observed that when the letters were presented serially, the “crossmodal” transfer (priming) of memory was comparable to that seen following within-modal priming. That is, the participants more often used the previously presented words in order to complete the three-letter word stems when the previously presented letters were used, no matter which sensory modality they had formerly been presented in (see also Bushnell & Baxt, 1999). Although this result might be taken to suggest the presence of shared representations for different sensory modalities (that can be accessed by different forms of input; i.e., visual or tactile), the nature of these representations is still a matter of some debate amongst researchers. In particular, it might be thought that after the stimuli are first processed by each sensory system individually, the information that is actually stored is semantic in nature rather than geometric, visual, or even more abstract in form (see Easton et al., 1997, on this point). Different results might therefore be expected when non-verbal stimuli are used instead (such as, for example, unfamiliar 2- or 3D objects; e.g., Norman, Phillips, Holmin, Norman, Beers, Boswell, et al., 2012).

The nature of the representations that are retained when visual or haptic materials are presented constituted the object of a series of studies reported by Lacey and Campbell (2006). These researchers used an interference technique in order to determine whether people’s memories for visual and tactile stimuli rely on amodal and/or verbal representations (see also Garvill & Molander, 1977; Millar, 1972, 1975a). The participants in Lacey and Campbell’s study had to look at (visual encoding) or feel (haptic encoding) a series of familiar and unfamiliar objects and try to remember them when performing a subsequent recognition test. The participants were explicitly told that visual encoding could be followed by haptic recognition or vice versa. They were also informed that during the encoding stage of the experiment, different distractors might be presented. Specifically, during the visual-interference condition, the participants also had to look at a visual display that showed irrelevant information (dynamic visual noise). In the verbal interference condition, the participants were instructed to listen to a pre-recorded text whose content was irrelevant to the task at hand. Finally, in the “haptic” interference condition, the participants were told to keep an irrelevant object moving in their non-dominant hand whilst either looking at the objects or feeling them with their dominant hand.

The results revealed that their participants’ ability to recognize unfamiliar objects was disrupted by both visual and verbal interference, whilst the recall of familiar objects was unaffected by all forms of interference. The authors took this result to suggest that the representation of unfamiliar objects may be *verbal* in nature. It is worth noting here that Lacey and Campbell’s (2006) results appear to be consistent with the model of object representation put forward by Johnson et al. (1989), one that assumed a serial/cascade process in which haptic inputs activated tactile representations. These, in turn, activate visual representations, and, if the object is familiar, the activation spreads to the verbal code, triggering the name of the object (and thus allowing the person to name it correctly; see also Spence & Deroy, 2013). Lacey and Campbell questioned whether the second stage of object representation following the tactile input is actually visual or spatial in nature. That is, is it the visual or rather the spatial information regarding the visual stimuli that caused the crossmodal interference effects that they observed? See also Stoltz-Loike

and Bornstein (1987, and Chapter 4) for the suggestion that spatial information is strictly linked with our awareness of tactile information.

The recognition of complex artificial layouts via different sensory modalities was investigated by Newell et al. (2005). In a series of experiments, participants first had to learn a scene composed of different numbers of objects arranged in random positions. After this learning phase of the study, the experimenter swapped the position of two of the 15 objects in the scene and had the participants identify which objects had changed position. The presentation of the displays containing the swapped objects could either occur in the same modality as the stimuli had been presented in originally (e.g., visually), or else in the other modality. Note that when the initial presentation of the scene occurred in the visual modality the participants were given 10 seconds in which to explore the objects, whereas they were given 60 seconds to explore the display haptically. This procedure was adopted in order to compensate for the longer exploration time required by the (“serial”) haptic modality as compared to the (“parallel”) visual modality. The results revealed that when there was a change in both the sensory modality and the orientation of the scene between the learning and test phases of the experiment, performance in the recognition task deteriorated (as compared to the condition in which there was no change of sensory modality between learning and test).

Newell et al. (2005) interpreted the difference between crossmodal and within-modality performance in terms of possible differences in the way in which spatial layouts are represented visually versus haptically. More specifically, the authors claimed that the previously reported systematic distortions in the haptic representation of space (i.e., researchers have reported that haptic space becomes more compressed as one moves away from the body midline; e.g., Kappers, 1999; Kappers & Koenderink, 1999) might have affected their participants’ performance in the crossmodal recognition task. This observation might be taken to suggest that different representations are used to store information regarding haptic as compared to visual scenes. It is, however, important to note that systematic distortions of haptic performance do not necessarily require the assumption of purely modality-specific representations (e.g., Nefs, Kappers, & Koenderink, 2002). Finally, it should also be borne in mind here that Newell et al. ruled out the possibility that the scenes were coded verbally by asking their participants to perform an articulatory suppression task during the learning of the stimuli (this procedure, consisting of the continuous repetition of the same word, which was assumed to interfere with the conversion of haptic and visual material into a phonological code; e.g., Gilson & Baddeley, 1969).

A number of studies published over the last decade have shown that multisensory experiences can influence current unisensory processing and memory performance (e.g., Butler & James, 2011; Lehmann & Murray, 2005; Murray, Michel, Grave de Peralta, Ortigue, Brunet, Gonzalez Andino, & Schnider, 2004; Thelen, Cappe, & Murray, 2012). In particular, Lehmann and Murray (2005) reported that repeated images are better discriminated if initially presented as auditory-visual pairs, rather than only visually. Although this multisensory enhancement of memory traces has only been demonstrated previously for audiovisual stimulus pairs, there would seem to be no obvious reason why a similar effect shouldn’t also be expected for visuotactile or audiotactile pairs of stimuli (or even for trimodal multisensory stimuli having visual, auditory, and tactile attributes) as well. The results of the studies summarized in this section, highlighting the interaction between people’s memories for stimuli presented in different sensory modalities, lead to at least three important conclusions: (1) Multisensory experiences lead to “richer” memories (i.e., the information that they contain can be easily been accessed from, and propagate between, different sensory modalities; see Lehmann & Murray, 2005; Murray et al., 2004); (2) The presentation of tactile information may help people to retrieve the multisensory qualities of the objects and

stimuli that they interact with haptically; (3) Differences might be present in the way in which people code (and store) memories for objects that they have seen visually as opposed to those objects that have been experienced solely by means of the sense of touch.¹

The studies presented in this section also highlight the fact that it remains unclear what representation is used for the storage of multisensory material regarding a given stimulus. Indeed, one may wonder whether inputs from different sensory modalities converge in amodal/multisensory neural storage structures (such as has been reported for the processing of the visual, auditory, and tactile stimuli, e.g., Fogassi, Gallese, Fadiga, Luppino, Matelli, & Rizzolatti, 1996; Lacey & Sathian, 2011) or whether instead a distributed network connecting unimodal storage structures is involved in the representation of multisensory stimuli (cf. Allman & Meredith, 2007; see also Lacey et al., 2007). That is, shared representations might arise from the cross-talk (or spread of activation) between the structures that are involved in the processing/representation of the unisensory qualities of the stimuli, or rather, they may have their own independent status and neurological substrate. In other words, another important question that researchers will have to address in the years to come is whether unisensory inputs converge on amodal/multisensory neural representations (or pools of neurons; e.g., Zhou & Fuster, 1997) or whether instead unisensory inputs (e.g., from visual information) automatically activate a network that connects many different unisensory neural representations (e.g., regarding visual, tactile and auditory information; e.g., Johnson et al., 1989). It may, of course, turn out to be the case that different task demands might even result in different ways of storing tactile and multisensory information in the brain (i.e., highlighting the complexity of our neural systems for memory storage).

Our summary of the research in this section highlights the fact that while various different studies have investigated the nature of people's tactile representations of real objects (something that might be thought to correspond to a form of "semantic" memory) virtually no research has addressed questions related to more "autobiographic" forms of tactile memory (e.g., Rubin, Schrauf, & Greenberg, 2003). That is, in no study so far (excluding sporadic anecdotal reports; e.g., see Katz, 1925; see also Virginia Woolf, 1985, quoted in Kwint, 1999), were the participants explicitly asked to recollect information regarding their previous life experiences with tactile stimuli/sensations. Moreover, to date, most studies have failed to investigate retention over intervals that were any longer than a few hours in order to investigate the constraints on the long-term representation of haptically explored objects. Finally, there is still virtually no published research on the question of how tactile memories deteriorate over time and whether the pattern of deterioration observed for this form of memory is correlated with the pattern of deterioration observed when visual and verbal materials are presented (note that a robust correlation would be consistent with the multisensory/amodal representation of objects). These important issues will need to be addressed by researchers if we want to fill the gap between our current knowledge regarding the visual and auditory aspects of memory and those relating to its tactile aspects.

5.3.2 Haptic memory for human faces

In the literature on visual perception, human faces have typically not been treated as generic objects but rather as a special category of stimulus (see Farah, Wilson, Drain, & Tanaka, 1998; Nachson, 1995). The special status of faces as compared to other objects appears to be justified

¹ One might wonder if this result might be due to the fact that while visual stimuli tend to be shown from only a single orientation, tactile stimuli when haptically explored may be felt from a variety of different orientations.

by the observation that certain brain areas, such as the fusiform gyrus, are specialized for the processing of faces (e.g., Haxby, Hoffman, & Gobbini, 2000; Kanwisher, McDermott, & Chun, 1997; Nasr & Tootell, 2012). Although faces can obviously be recognized both visually and haptically, little research has thus far attempted to investigate how the tactile system can be used to process and remember faces (e.g., Dopjans, Bülthoff, & Wallraven, 2012; Kitada, Johnsrude, Kochiyama, & Lederman, 2010; Klatzky & Lederman, 2011; Lederman, Klatzky, Abramowicz, Salsman, Kitada, & Hamilton, 2007; Lederman, Kilgour, Kitada, Klatzky, & Hamilton, 2007).

In one of the studies that have investigated the topic of haptic face recognition, Kilgour and Lederman (2002) asked their blindfolded participants to perform a matching-to-sample tactile recognition task, where human faces were used as stimuli (note that the possible use of auditory and olfactory cues was prevented by the use of white noise and nasal ointment, respectively). In the first part of the experiment, the participants had to familiarize themselves with the target face (chosen from a set of 15 real human faces) by means of manual exploration. After completing the encoding phase of the study, the participants had to try and discriminate which face had previously been presented from among a set of two distractor faces.

The results showed that the blindfolded participants were able to identify the standard face from among the three comparison faces (i.e., two distractors and one target) with an accuracy that exceeded 80% correct (where chance level performance would have given rise to 33% correct responses; see also James, Servos, Huh, Kilgour, & Lederman, 2006; Kilgour, de Gelder, & Lederman, 2004, for similar results). Interestingly, Kilgour and Lederman also reported that there was no correlation between the ability of their participants to use visual imagery (as assessed by means of the Visual Imagery Questionnaire, VVIQ; Marks, 1973) and the matching accuracy or total response time. On the basis of this result, Kilgour and Lederman went on to conclude that the haptic representation and recognition of human faces was not necessarily mediated by visual information.

Kilgour and Lederman (2002) also had their participants report which cues they had used in order to identify the standard face from amongst the distractors. The results revealed that participants in their first experiment reported having used approximately 70% geometric properties (e.g., the global shape of a face, the relative position of the eyes, the length of the nose, etc.) and 30% material properties (e.g., smoothness and softness of the skin). These results therefore suggest that both the macrogeometric (i.e., spatial layout) and microgeometric properties of a face are stored in order to support subsequent recognition. However, the macrogeometric properties of the stimulus would appear to have been used more often than the microgeometric properties in order to perform the task. This could perhaps be due to a more global (rather than local) form of processing, one that has often been considered peculiar to visual facial recognition (e.g., Bartlett & Searcy, 1993).

Taken as a whole, the results of the majority of the studies summarized thus far in this section suggest that similar processes (not necessarily mediated by vision, but perhaps by spatial or amodal stimulus representations) may be common to the processing and storage of both haptically and visually presented faces. Interestingly, this claim has garnered empirical support from studies of those neurological patients who have been affected by prosopagnosia (a neurological disorder caused by brain damage in which patients fail to recognize faces, even those that are very familiar to them; e.g., De Renzi, 1986; Farah, Levinson, & Klein, 1995). Specifically, Kilgour et al. (2004) tested haptic face recognition in a prosopagnosic patient suffering from the effects of a lesion of the fusiform gyrus. Their hypothesis was that if face processing was specific to vision then the patient should not show any difficulty in processing faces haptically. Surprisingly, the

ability of the patient to perform haptic face recognition was impaired by the same manipulations that have previously been shown to impair visual face recognition (such as the inversion of the face; see Valentine, 1988). This result might be taken to support the view that the neural processing system thought to be involved in the representation of faces (involving the fusiform gyrus) is shared between different sensory modalities (the fusiform gyrus is functionally connected with both occipital and parietal brain areas; e.g., Bokde, Lopez-Bayo, Meindl, Pechler, Born, Faltraco et al., 2006). That is, representations of facial information might be, at least in part, amodal rather than modality-specific (although each modality may be better able to store particular facial properties, such as color for vision, and texture or temperature for touch; see Casey & Newell, 2007).

Further confirmation of the possibility that information regarding the tactile characteristics of faces might involve similar brain structures to those involved in the storage of visually presented faces also comes from a neuroimaging study reported by James, Kilgour, Servos, Kitada, Huh, and Lederman (2006). In this experiment, a significant increase of activation was observed in the *left* fusiform gyrus when their participants haptically explored facemasks as compared to control objects (see also Lederman et al., 2007, for a review on the neural mechanisms of haptic face processing). The authors concluded that this left fusiform activation (as compared to the right activation following the visual presentation of faces) might represent the “sequential/serial” modality of information processing that characterizes the left hemisphere (as compared to a more global processing of the right hemisphere; see Robertson, Lamb, & Zaidel, 1993). However, before drawing any firm conclusions based on the data reviewed in this section, it should be noted that the activation of the same brain structures in visual and tactile face representation might, at least in part, be mediated by possible strategies involving the deployment of visual imagery (see also section 5.3.4 on tactile memory and mental imagery). We would argue that further studies are therefore needed in order to address the role of the fusiform gyrus and other brain structures in the storage of tactile as well as visual information regarding faces and the lateralization of such a neural network. As far as this point is concerned, Kitada, Johnsrude, Kochiyama, and Lederman, (2009) used fMRI to study and compare the brain organization underlying the haptic and visual recognition of human body parts, comprising faces. They identified two discrete regions within the fusiform gyrus that were each sensitive to both haptically and visually presented faces. Although their results clearly indicated that the occipito-temporal region plays an important role in haptic, as well as visual, recognition of human faces and other body parts, the authors also found that within these brain areas there are subregions that are most sensitive to haptic input and others that are most sensitive to visual input. That is, a part of neural activity involved in processing and recognizing faces appears to be sensory specific while other parts are more multisensory in nature.

Finally, additional research is going to be needed in order to address the question of whether the way in which haptic information is gathered affects the encoding and storage of that information in the brain (i.e., a question that is related to the “serial” versus “parallel” manner of perceiving tactile stimuli and to the well-known hemispheric specialization for serial versus parallel processing; e.g., Robertson et al., 1993).

5.3.3 Haptic memory for the body?

Kaitz and colleagues (Kaitz, 1992; Kaitz, Lapidot, Bronner, & Eidelman, 1992; Kaitz, Meirov, Landman, & Eidelman, 1993; Kaitz, Shiri, Danzinger, Hershko, & Eidelman, 1994) have conducted a number of studies in which the participants had to identify, from amongst a group of distractors, their romantic partners or their newborn infants solely by haptic exploration. In one

such study, Kaitz reported that participants could accurately recognize their partner among two other distractors simply by touching the dorsal part of the hand or a small portion of their forehead in 58% of the trials (i.e., at a level that was significantly above chance; Kaitz, 1992). Although both the male and female participants could identify their opposite-sex partners by touching the forehead, only the female participants were able to recognize their partners at a level that was significantly above chance by touching the back of their hand. Kaitz concluded that men have more differentiating characteristics (e.g., hair) on their hands. The overall conclusion from Kaitz's work was that tactile cues are sufficient to allow for the recognition of highly familiar individuals (note that in Kaitz's, 1992, study, as in the subsequent studies by the same group, identification based on olfactory cues was prevented by means of closing the participants' nostrils with a noseclip).

In three subsequent studies (Kaitz et al., 1992, 1993, 1994), the parents of newborn infants had to try and identify their infants haptically from among three distractor babies. In these studies, the parents were only allowed to touch the dorsal surface (i.e., the back) of the hand or cheek. Although the parents could not identify their own infant, with whom they had had less than 1 hour of contact, they were able to identify infants as young as 7 hours old. The participants in these experiments identified two material characteristics, texture and temperature, as the most salient diagnostic characteristics. Note that the results of these studies showed that people can correctly recognize tactile stimuli concerning highly specific human features after a relatively short exposure period (see also Bader & Phillips, 1999); But what about recognizing one's own body?

Throughout our lifetimes, we build, store, and update a representation of the way that our body appears from the outside, the so-called "body image" (see the distinction between body image and body schema outlined in Chapter 2; see also Chapter 8). In order to recognize a visually presented body part, we need to compare the external stimuli with the representation of our body stored in our brains. A difficulty in recognizing the parts of our own body when presented visually has been reported in conditions such as anorexia nervosa (e.g., Bruch, 1962). Moreover, patients with right hemisphere brain damage and, in particular, those affected by unilateral spatial neglect, may sometimes fail to recognize their paretic limb as a part of their own body; a disorder known as somatoagnosia (see Bisiach & Vallar, 2000; Rubio & Van Deusen, 1995; Vallar, 2001; see also van Stralen, van Zandvoort, & Dijkerman, 2011). Surprisingly, Willemin and Richardson (1982) reported that even neurologically normal participants may fail to recognize the back of their own hand when presented visually among other objects when they were unaware that their hand might appear in the set of photographed items (see also Holmes, Farnè, Rode, & Rossetti, submitted, for a task where neurologically normal participants were required to determine whether or not a visually presented hand belonged to them or to another person).

The failure to recognize one's own body parts by touch alone appears to be more complex to study, as compared to the study of visual recognition of the body, and perhaps as a consequence, very little research has been directed to this topic. Specifically, important methodological constraints limit the study of body recognition by means of the sense of touch. Indeed, if a participant is instructed to recognize their own body by active exploration, it will obviously be difficult to differentiate between the various different sources of information processed in order to perform the task. That is, the processing of inputs (somatosensory, kinesthetic, and proprioceptive) from the part of the body that is used for the scanning procedure and the processing of somatosensory inputs from the part of the body that is touched in the limb recognition process cannot easily be analyzed separately (at least if the touched limb is not anaesthetized or very accurate reproductions of people's limbs are used). As a consequence, the results of the few studies that have attempted to investigate the recognition of a person's own body-parts by touch might be

somewhat more complex to interpret as compared to the more straightforward interpretation of the studies that investigated visual body parts recognition (e.g., Holmes et al., submitted).

A disorder affecting the ability of people to identify which finger has been touched, known as “finger agnosia” sometimes occurs after lesions of the left parietal lobe, and more specifically after lesions of the angular gyrus (e.g., Anema, Kessels, De Haan, Kappelle, Leijten, Van Zandvoort, & Dijkerman, 2008; Kinsbourne & Warrington, 1962; see also Rusconi, Walsh, & Butterworth, 2005, for disruption of finger identification after temporary interference by repetitive transcranial magnetic stimulation (rTMS) over the left angular gyrus in neurologically normal participants). Patients with this disorder can correctly report the presence of tactile stimuli on their fingers but they cannot identify correctly which of their fingers had actually been stimulated by the experimenter. Although this deficit might appear *prima facie* to be related to damage to a haptic representation of the fingers, the deficit might also be related to the *access* to an intact, perhaps multisensory, representation of the fingers.

Surprisingly, the occurrence of other disorders, such as somatoparaphrenia, that involve a failure to recognize the contralesional parts of one’s own body (e.g., Invernizzi, Gandola, Romano, Zapparoli, Bottini, & Paulesu, 2013; Vallar & Ronchi, 2009), has rarely been investigated using haptic exploration procedures in neurological patients (for example, by asking a blindfolded patient whether or not the self-touched paretic limb is part of his/her body or not). In what to our knowledge is the sole report of haptic self-touch having been tested in a patient suffering from somatoparaphrenia, van Stralen and his colleagues (2011) asked the patient to stroke their own impaired left hand as well as the hands of another person. The results of this study revealed that the patient reported ownership (as well as a change in affect) over all presented hands through self-touch. On the basis of this observation the authors concluded that self-touch can modulate impairments in body ownership. Note, however, that as a consequence of the fact that the patient extended the sense of ownership toward “all” the touched hands, this study does not really shed any light on the matter related to our understanding of the haptic representations of the body.

5.3.4 Mental imagery and tactile memory

In this section, those studies that have addressed the question of the role of mental/visual imagery on tactile memory are reviewed. In the majority of the studies reported in this section, the participants had to actively explore certain objects using their hands and then to perform a task thought to involve the deployment of mental imagery on the representation of the previously explored stimuli (see Gallace, 2013, for a review of somatosensory mental imagery). The results of these studies highlight the fact that mental imagery (mediated by spatial or visual codes) is used by both sighted and congenitally blind individuals in order to process certain aspects of tactile stimuli (suggesting that tactile information can be translated into a visual/spatial code). This, once again, appears to highlight the fact that multisensory processing affects the representation of haptically explored objects in the human brain (see also Spence & Deroy, 2013, on the concept of crossmodal mental imagery).

Whenever we see a previously seen object, we tend to recognize it immediately, presumably because the various features of the object activate a given population of neurons (or neural representations) in the brain. This neural representation is built up as an abstraction of all of the experiences that we had with that specific object and it thus enables us to recognize the object as being unique (even when seen from a different perspective). However, we can also “see” the same object with our eyes closed. In this case, the same visual representations appear to be activated in the

absence of any external stimulation. This is known as “visual imagery” (see Kosslyn, 1994). Earlier, we discussed whether the nature of tactile memory is actually visual, tactile, verbal (semantic), or amodal in nature. In this section, we will review the literature that has investigated the role of visual imagery in tactile memory.

The study of visual imagery is particularly relevant to the topic of tactile memory given the demonstration by Paivio (1986) that producing mental images of stimuli (such as words) facilitates their recall. Paivio also pointed out that imagery can be derived from all the sensory modalities and therefore that congenitally blind people could form mental images of objects based on their intact sensory modalities (see Renzi, Cattaneo, Vecchi & Cornoldi, *in press*). On the basis of such considerations, one might therefore wonder whether visual/mental imagery may also play an important role in the recall of tactile information for sighted and visually impaired individuals (see Lacey, Flueckiger, Stilla, Lava, & Sathian, 2010; Lacey & Sathian, 2012).

Aleman, van Lee, Mantione, Verkoijen, and de Haan (2001) investigated the capacity of congenitally blind individuals to perform tasks thought to be mediated by visual mental imagery in sighted individuals (see also Arditi, Holtzman, & Kosslyn, 1988; Kerr, 1983; Uhl et al., 1994). The participants in their study had to perform two tasks: A pictorial task, involving the mental comparison of the shapes of objects and a spatial task in which they had to imagine a path through haptically explored 2D and 3D matrices. It is worth highlighting here that in order to perform these tasks correctly both required the functioning of a working memory system, one that temporarily retains information regarding the objects or locations that have been explored previously. The results showed that although the blind participants performed somewhat less accurately than the sighted participants, they were nevertheless still able to perform both tasks reasonably successfully (see also De Volder, Toyama, Kimura, Kiyosawa, Nakano, et al., 2001, for the report of neural activation in the occipito-temporal and visual association cortical areas of early blind participants when they were asked to perform a task involving visual imagery, such as imagining an object’s shape, following the presentation of an auditory cue). This result can be taken to suggest that mental “images” can be used by both the sighted and the blind in those tasks requiring the comparison of object representations held temporarily in working memory. Moreover, the apparent similarity between the performance of the sighted and blind participants in these kinds of tasks has led to the suggestion that imagery representations rely very little on vision and are instead crossmodal in nature (e.g., De Beni & Cornoldi, 1988).

Other studies, meanwhile, have demonstrated that the blind experience mental imagery, although their ability to use specifically visual imagery decays with time in the case of acquired blindness, and is probably absent in those born blind (e.g., Hollins 1989; see also Cattaneo & Vecchi, 2011). Blindness, especially when congenital, slows the performance of tasks requiring the mental rotation of tactile stimuli (e.g., Marmor & Zaback, 1976; Ungar, Blades, & Spencer, 1995). For example, Marmor and Zaback presented congenitally blind and blindfolded sighted participants with a mental rotation task in which two consecutively presented 3D displays had to be compared. In this task, the second display was typically oriented at a different angle from the first across the three main rotational axes. Generally, when this task is presented visually, the latency of a participant’s responses is linearly related to the degree of rotational misalignment between the two patterns (i.e., the more the two stimuli are misaligned, the slower the reaction time (RT); see Shepard & Metzler, 1971; Wohlschläger & Wohlschläger, 1998). This result has generally been taken to provide evidence that participants have to create, hold in memory, and imagine the rotation of a mental image of the stimuli in order to compare the two visually presented displays (e.g., Kosslyn, Behrmann, & Jeannerod, 1995; though see Kosslyn, 1983; Kubovy, 1983; Rock et al., 1989).

Marmor and Zaback's (1976) results provided evidence for the mental rotation of these stimuli in both congenitally blind and sighted individuals. In particular, by using a matching task between pairs of 3D tactile stimuli they reported the same relation between RT and angular disparity of the target shape as in the original experiment by Shepard and Metzler (1971). However, Marmor and Zaback also reported that the blindfolded sighted participants responded more rapidly overall (and made fewer errors) as compared to the blind participants (though see Carpenter & Eisenberg, 1978). These results were taken to suggest that while the congenitally blind do form mental images which are functionally equivalent to those of the sighted, visual images may simply be easier to manipulate than haptic images. It is, however, important to note here that using exactly the same task, Carpenter and Eisenberg failed to observe better performance in the sighted than in the blind. These researchers suggested that this apparent discrepancy might be due to possible differences in the amount of previous experience that congenitally blind participants may have had with tactile graphical materials (i.e., tactile reproductions of visual images).

Research on the topic of mental imagery in sighted participants highlights the fact that while blindfolded participants are perfectly capable of generating and scanning small size mental maps based on haptic exploration, they suffer from a reduced ability to generate precise spatial representations of full-scale navigable space (e.g., created by an immersive audio virtual reality system; see Afonso et al., 2010). This might be taken to suggest that the generation of mental images on the basis of haptic and locomotor input by sighted participants might be more limited than the ability to generate these images when visual and verbal input are provided. As a consequence, one should conclude that the mental imagining based on visual inputs (more than haptic input) does indeed facilitate the storage of multisensory (visuohaptic) information regarding navigable spaces.

As far as possible, differences between visual imagery in blind and sighted individuals is concerned, Cornoldi, Cortesi, and Preti (1991) have suggested that blind individuals may have visuospatial imagery processes but that they suffer from some capacity limitations in their short-term visuospatial memory. Note, however, that similar limitations (although reduced in magnitude as compared to those found in the blind) as well as individual differences have also been reported in the sighted (e.g., Cornoldi et al., 1991; see also Cornoldi & Mammarella, 2006; Cornoldi & Vecchi, 2003; Dalton et al., 2009). One should also consider the fact that different studies have revealed that blind people have difficulty coping with rotations at oblique orientations (e.g., Millar, 1976). Using a task involving the recognition of rotated drawings, Millar reported that those participants who were totally blind were worse than the sighted at oblique rotations but not at orthogonal rotations (e.g., 90 and 180 degrees of rotation). She also suggested that congenital blindness reduces access to cues regarding frames of reference and that the frames of reference used by the congenitally blind may be less well specified than those used by the sighted (see also Röder, Kusmierek, Spence, & Schike, 2007).

Finally here, it should be noted that a study by Ungar, Blades, and Spencer (1995) in which the performance of visually impaired children was tested using a task that involved the mental rotation of tactile layouts (composed of five clay shapes such as a square, circle, triangle, cross, and star), revealed that the accuracy of the children's performance was correlated with the specific strategy that they adopted to perform the task. In particular, those children who tried to relate the elements of the display to each other, and to the frame of the display performed better in the task.

Taken as a whole, the results of the studies reported in this section therefore suggest that mental imagery (especially visual imagery in sighted individuals; see Afonso et al., 2010) can facilitate certain aspects of tactile perception and memory (such as under those conditions in which information regarding the presented stimuli needs to be compared with information that

has been previously presented by using a different perspective; this might be the case for maps) in both sighted and visually impaired individuals. It is, however, worth mentioning that it is still a matter of some debate as to whether the contents of these mental representations (that are thought to mediate performance in mental imagery tasks, especially in congenitally blind individuals) are actually visual or rather spatial in nature (see Bertolo, 2005, on this point; see also section 5.2). What is more, we know very little about how potential differences in people's ability to generate mental images in different sensory modalities can affect tactile memory (see Olivetti Belardinelli, Palmiero, Sestieri, Nardo, Di Matteo, Londei, D'Ausilio, Ferretti, Del Gratta, & Romani, 2009).

5.4 Tactile memories in the blind

In this section, we review those studies that have investigated tactile memory in blind individuals. These studies have used tasks in which the participants were asked to haptically explore and remember 3D objects and/or Braille characters. The evidence gathered so far by researchers would appear to suggest that multisensory (verbal and/or spatial) representations are also required in blind individuals for the storage of haptically explored stimuli.

One might therefore wonder whether differences (in capacity, duration, and/or vividness) should be expected between sighted and visually impaired individuals' memory for tactile stimuli. Indeed, visually impaired individuals are generally more experienced in recognizing stimuli by touch/haptics as compared to the sighted (see Saito, Okada, Honda, Yonekura, & Sadato, 2007). What is more, the research that has been conducted to date has revealed that any visual deprivation occurring at an early stage of development may lead to the reorganization of the visual cortex (the area of the brain that is normally responsible for the processing of visual stimuli). In particular, the visual cortex is known to be activated when blind participants perform tactile tasks such as Braille reading (e.g., Sadato, Pascual-Leone, Grafman, Ibanez, Deiber, Dold, & Hallett, 1996; see also Buchel, Price, Frackowiak, & Friston, 1998; Cohen, Celnik, Pascual-Leone, Corwell, Faiz, Dambrosia, Honda, Sadato, Gerloff, Catala, & Hallett, 1997; see also Cattaneo & Vecchi, 2011, for a recent review). These effects appear to be related to the fact that the visual cortex, which is normally responsive to stimulation in one sensory modality (vision), can respond to inputs from other sensory modalities, such as touch (e.g., Pascual-Leone, Wassermann, Sadato, & Hallett, 1995; see also Ortiz-Terán, Turrero, Barcia, Nogales, Calvo, Martínez, Córdoba, & Pascual-Leone, 2011; Vasconcelos, Pantoja, Belchior, Caixeta, Faber, Freire, et al., 2011). Following on from these observations, one might expect there to be differences between the tactile memory abilities of sighted versus visually impaired individuals.

In an early study addressing this very question, Millar (1975a) investigated the tactile memory abilities of a group of congenitally totally blind children. The blind participants in her study (children at different stages of learning Braille) had to try and recall lists of Braille patterns that were presented sequentially in their correct order of occurrence. After the presentation of the lists, the children had to point to the serial position that a given test pattern had occupied in the target memory series (a task that was designed to test the participants' memory "span"). Critically, the lists of to-be-remembered items were: (1) composed of tactually similar stimuli; (2) composed of stimuli that had similar sounding names; or (3) composed of stimuli that were dissimilar on both of these dimensions. Millar's results revealed that recall was impaired by both tactual and verbal similarity. However, phonological (verbal) similarity was found to have a more detrimental effect on performance for those children who showed faster naming latencies for the Braille items that had been presented in a pre-test part of the experiment. By contrast, the performance of those

children who were slower at naming in the pre-test session, were found to be more impaired by tactual similarity. This result would appear to suggest that after the tactile materials have been associated with specific phonological codes, they were stored in this verbal/amodal form by the visually impaired individuals in this study.

Possible differences between the tactile memory of the sighted and visually impaired have also been investigated by Arnold and Helron (2002). These researchers asked two groups of participants (ten deaf-blind and ten sighted-hearing participants) to complete different memory tests in four consecutively presented experiments. The participants had to identify complex objects (experiment 1; or “dominos,” experiment 2) previously explored haptically for 2 minutes when presented among a group of distractors (this is what is known as a recognition memory test). In their third experiment, the participants had to try and remember the positions in which a number of coins had been placed in a 2-by-2 or 3-by-3 matrix (this is known as a spatial recall memory test). In a final experiment, the participants played a tactile textured version of the game “matching pairs” (requiring the recall of the position of those pairs of cards having the same texture within a 4-by-3 matrix). The sighted-hearing participants were all blindfolded before the memory tests began.

The results of the four experiments reported by Arnold and Helron (2002) revealed that the deaf-blind participants took less time than the sighted-hearing participants in order to feel and remember the target stimuli. The mean time taken by the participants in order to complete the recall tasks was also significantly reduced for the deaf-blind as compared to the sighted-hearing participants. Finally, the deaf-blind participants also took less time and made fewer attempts to complete the “matching pairs” game. It is, however, worth noting here that the mean performance in the various tasks did not differ between the two groups of participants in terms of the number of errors that they made. That is, while the deaf-blind participants performed more rapidly than the sighted-hearing participants, they did not necessarily perform any more accurately. On the basis of these results, Arnold and Helron went on to conclude that the deaf-blind participants’ encoding of tactile information was more efficient than that of the sighted-hearing participants, and that it was probable that their short-term storage and retrieval were normal. This view appears to be consistent with Rönnerberg’s (1995) claim that compensation of a deficit by means of unrelated cognitive functions or sensory substitution rather than perceptual compensations accounts for the improvement in performance seen in sensory impaired individuals in different tasks.

The results of a neuroimaging study reported by Saito and colleagues (2007) also revealed the activation of V1 in a tactile discrimination task performed by sighted individuals (see also Vasconcelos et al., 2011, for the observation that during the free exploration of novel objects by rats, V1 and S1 responses carried comparable amounts of information). Critically, however, this activation of visual areas was only found for those participants who had been trained in tactile discrimination (e.g., players of mah-jong who happened to be expert in discriminating the tiles that are used to play the game). Interestingly, the enhanced activation of V1 in the expert group in this study was also reported (although reduced in magnitude) when Braille characters were presented, thus showing that the effect extended beyond the specific category of expertise of the participants. In order to interpret the latter result, Saito et al. suggested that crossmodal plasticity resulting from the effects of long-term training on one set of cards (mah-jong) generalized to an untrained set of cards (Braille). These results can therefore be taken to suggest that the involvement of visual areas when participants perform tactile tasks (a result previously observed only in blind individuals; e.g., Sadato et al., 1996), might, at least in part, be related to the strengthening of crossmodal connections/representations as a function of intensive practice. That is, people who are experienced with a certain class of visual stimuli may learn to associate those stimuli with their

tactile equivalent. This would also result in an activation of visual areas when the stimulus is presented haptically (cf. Murray et al., 2004, 2005). On the basis of such observations, one might even wonder whether practice with tactile materials in sighted individuals can affect their memory for tactile information (see Behrmann & Ewell, 2003, for the role of practice on the tactile identification of 2D patterns).

5.5 The development of haptic memory

In this section, we review the few studies that have investigated the topic of haptic memory in infants. The research discussed here, just as for that presented in the preceding three sections, made use of the haptic exploration of objects by participants. The evidence arising from these studies shows that tactile representations are already present at a very early age. More importantly, the presence of these early tactile representations in infants rules out the possibility that the code used to store tactile stimuli is semantic in nature, but does not necessarily shed any light on whether a unisensory rather than a multisensory/amodal neural code is used for the storage of haptically explored objects/shapes.

As previously mentioned (see Chapter 1), the tactile modality is the first sense to develop and just before the 8th week of gestation, embryos develop a sensitivity to tactile stimulation (e.g., Atkinson & Braddick, 1982; Bernhardt, 1987; Bremner et al., 2012; see also Lejeune, Audeoud, Marcus, Streri, Debillon, & Gentaz, 2010; Marcus, Lejeune, Berne-Audéoud, Gentaz, & Debillon, 2012; for the tactile abilities of pre-term infants). Unfortunately, nothing is currently known about those aspects of these very first tactile experiences that may be retained after birth or whether or not they can affect the successful functioning of the tactile system in adults. The haptic memory for previously touched objects has instead been studied in infants of a few months of age. Research on infants is of particular importance to the study of tactile memory since it has allowed researchers to investigate the more “perceptual” (i.e., rather than “verbal/semantic”) representation of information. Researchers can be sure that linguistic representations of tactile objects will certainly not have developed in babies of only a few months of age.

In one study, Catherwood (1993) tested recognition memory for the tactile qualities of manipulated objects, such as the shape and texture, in a group of 8-month-old infants. The 48 infants in this study were first familiarized haptically to a small cube or sphere with a smooth or rough surface texture (the encoding part of the experiment). The infants were then tested for their ability to “recognize” the shape and texture of this stimulus when it was presented amongst a set of distractors. In order to determine whether or not the infant correctly recognized the previously presented stimuli, the average contact time for each stimulus (including both the target and the distractors) was measured. Note that using this particular paradigm, correct recognition was inferred from a contact time for the target stimulus that was shorter than that for the distractors (infants typically explore novel objects for longer than for objects with which they have been previously familiarized).

Different conditions of post-familiarization testing were adopted. Specifically, the test stimuli could either be presented immediately, after a 5-minute delay, or after an interference phase involving the presentation of another haptic stimulus that was different in both shape and texture from the first. Catherwood's results revealed that the infants correctly recognized the shape and texture of the target stimulus in the no delay condition, the shape and (to a larger extent) the texture in the delay condition, but only the texture in the interference condition. These results illustrate that some form of haptic memory already exists in 8-month-old infants (see also Lhote & Streri, 1998, for a study apparently showing haptic memory in even younger, 2-month-old, infants). These

memory systems are capable of sustaining haptic information over a brief delay and even in the face of intervening exposure to other haptic inputs. The information retained in these early (in terms of development) representations must clearly relate to the more perceptual and/or spatial, rather than semantic, aspects of the tactile stimulation (see Meltzoff, 1993; Meltzoff & Borton, 1979; Meltzoff & Moore, 1995; see Millar, 1974, 1975a, 1978b, for the study of tactile memory at later stages of development in both sighted and visually impaired children).

Importantly, a study by Sann and Streri (2007), directly investigated the presence of crossmodal transfer between vision and touch in the identification of objects by newborns. In this experiment, newborns of about 42 hours (and ranging from 18 to 85 hours), received a habituation phase, consisting of the presentation of 3D objects (a cylinder and a prism) in a first sensory modality (e.g., vision) followed by a test phase in the second modality (e.g., touch). The results revealed that newborns were able to correctly recognize visually a shape previously held, but that they failed to recognize by touch a shape previously explored visually. Such a result can be taken to suggest that early multisensory interactions in the storage of haptically explored stimuli occur in newborns (see Molina & Jouen, 2003; Sann & Streri, 2007; Streri & Gentaz, 2003, 2004; Streri, 2012, for evidence that newborns can visually recognize the shape of an object that they have previously manipulated with their right hand, out of sight). As far as this point is concerned, one might even expect that these multisensory interactions in the neural representations of haptic stimuli are more robust than those present in adult participants. Indeed, it has been claimed by certain researchers that multisensory neural connections are more widespread at the earlier stages of development (e.g., Maurer 1997; Maurer & Mondloch, 2005; Sarko, & Ghose, 2012; see also Burr & Gori, 2012, for a review on the development of multisensory integration).

5.6 An implicit memory for tactile sensations

In this section, the difference between implicit and explicit representation of information, largely investigated previously in studies of visual memory, will be addressed for the case of the tactile domain. The few studies that have investigated this topic in touch have tended to use the haptic exploration of objects and their results have highlighted the presence of presumably intact representations of haptically explored stimuli even when the content of these representations cannot be reported explicitly. Once again, we will highlight the fact that the nature of these representations remains obscure.

As reported in section 5.1, a clear distinction in the extant literature on memory has been made between implicit and explicit memory (e.g., Schacter, 1987; see also Yang & Li, 2012, for the different neural substrates underlying such memories). That is, the empirical evidence published to date suggests that information can be stored and retrieved regardless of people's awareness of it. In particular, the study of those patients suffering from amnesia has shown that they can correctly store different kinds of information, despite the fact that they may lack any awareness regarding its availability for explicit recall. This can be inferred indirectly from a change in their behavior attributable to the previous exposure to the stimuli. For example, amnesic patients can show implicit memory for events through their ability to learn new skills (e.g., Corkin, 1968; Gabrieli, Corkin, Mickel, & Growdon, 1993; Milner, 1962), or repetition priming (e.g., Gabrieli, Keane, Stanger, Kjølgaard, Corkin, & Growdon, 1994; Gabrieli, Milberg, Keane, & Corkin, 1990; Keane, Gabrieli, Mapstone, Johnson, & Corkin, 1995; Milner et al., 1968).

A classic anecdotal case of implicit learning was reported by Claparede (1911/1951). He concealed a pin in his palm before shaking the hand of an amnesic patient. On the day following this painful episode, the patient refused to shake the physician's hand, despite having no conscious

recollection of the incident. This example suggests that the patient had implicitly learned the association between the doctor and the painful stimulation (see Claparede, 1911/1951). Despite the fact that, in this classic example, a “painful” stimulus was presented to the patient’s skin in order to show implicit learning, most of the research that has followed on the topic has used visual materials instead.

Although the study of the implicit learning of complex motor sequences by patients suffering from amnesia clearly suggests that haptic as well as kinesthetic and proprioceptive information (i.e., information that is necessary for one to execute complex movements correctly) is stored regardless of people’s awareness, very little (if any) empirical research has directly addressed the question of whether or not implicit memory can also affect the processing of tactile information. Evidence suggesting that tactile information might be stored and retrieved implicitly comes from the study of the implicit processing of tactile stimuli in patients who are affected by unilateral neglect and extinction (e.g., Maravita, 1997).

As we saw in Chapter 3, Maravita (1997) described the case of a right-hemisphere brain-damaged patient affected by tactile extinction who showed an implicit retention of information regarding the size of objects previously held in his contralesional hand (even in the absence of an explicit report regarding the presence of such an object). This result suggests that, just as had been shown previously for the perception of visual or nociceptive stimuli, tactile stimuli are also encoded and stored in the brains of brain damaged patients in the absence of explicit awareness.

The implicit memory for tactile/haptic information has also been investigated in patients suffering from Alzheimer’s disease as well as in a sample of old and young neurologically normal participants (Ballesteros & Reales, 2004). In the “encoding” block of Ballesteros and Reales’s experiment, the participants had to haptically study a series of objects presented by the experimenter. The objects were presented in a randomized order, one at a time, on a platform located just behind an opaque panel (and so out of the participant’s view). The participants were allowed to explore each object for 10 seconds. A speeded recognition test (the implicit memory task) was then presented after a 5-minute break. The participants had to try and name each of the haptically presented stimuli, chosen from a set composed of 10 previously studied objects and 10 new objects, as rapidly as possible.

Response latencies were measured from the moment at which the participant’s hands touched the object to the onset of their naming response. In the final part of the study (the explicit recognition test), the experimenter placed a randomly selected object on the center of the platform and asked the participant whether the object was “old” (i.e., an object presented during the study phase) or “new” (i.e., an object that had not been presented during the first part of the experiment). Unsurprisingly, the results revealed that the accuracy of participants’ recognition performance was far worse in those patients suffering from Alzheimer’s disease than in the other two groups of participants (who did not show any significant differences in performance between them). However, more interestingly, the latency of participants’ responses in the implicit memory task revealed a significant benefit (i.e., their RTs were faster) for previously presented items as compared to new items in all three groups of participants.

On the basis of their results, Ballesteros and Reales (2004) went on to conclude that despite an impaired explicit recognition of previously presented items, Alzheimer’s patients can still exhibit intact haptic priming in a speeded object naming task. Interestingly, this priming effect did not differ from that obtained by either the older controls or by the young adults. It is, however, worth bearing in mind here that although Ballesteros and Reales’s results would appear to offer convincing evidence in support of the presence of an implicit form of memory for haptically explored objects (see also Reales & Ballesteros, 1999), their study does not shed any light on the question of

“what” it is, exactly, that is actually being implicitly stored by the patients. With regard to this latter point, it can be noted that the information that the participants stored in the implicit naming task used by Ballesteros and Reales (2004) might have been verbal or even visual, rather than haptic in nature. That is, the haptically presented information regarding the objects could easily, and perhaps automatically, have been converted into a verbal or visual representation (cf. Cornoldi, Cortesi, & Preti, 1991). As a consequence, in the naming task, the better performance observed in all groups of participants for those items that had been presented previously might have been attributable to the access to these non-haptic representations by haptic inputs. Alternatively, however, inputs from both vision and touch might perhaps have accessed an amodal object structural description system having its neurological substrate in the extrastriate cortex (e.g., James et al., 2002).

The use of tactile nonsense shapes and 3D stimuli that the participants find more difficult to represent by means of verbal/semantic or visual codes has offered researchers the opportunity to address this very topic (e.g., James, Humphrey, Gati, Servos, Menon, & Goodale, 2002; James, James, Humphrey, & Goodale, 2005; James, Shima, Tarr, & Gauthier, 2005; Norman, Phillips, Holmin, Norman, Beers, Boswell, Cheeseman, Stethen, & Ronning, 2012; see also Conway & Christiansen, 2005, for the use of tactile sequences of meaningless stimuli). Specifically, James and colleagues (2002) asked participants to visually explore a set of 16 nonsense 3D objects and haptically explore a separate set of 16 objects. After that, they had to perform a second experimental block while their brain activation was recorded using fMRI. During the scanning block, the participants were presented with visual images of the previously studied objects and an additional set of 16 unstudied objects. The researchers reported that previous experience with haptically presented objects enhanced brain activation in visual areas (i.e., the lateral occipital complex) when these same objects were subsequently viewed in the scanner. The authors concluded that object-representation systems in the ventral visual pathway may be exploited for haptic object perception. That is, shared representation systems may subserve memory for both visually and haptically explored objects. One might then wonder if the same concept can be extended to stimuli that are not explicitly reported by the participants (see Conway & Pisoni 2008, for discussion of this point).

There hasn't been all that much research investigating the implicit processing of tactile information in neurologically normal participants (e.g., Conway & Christiansen, 2005). In one of the few studies to have addressed this topic, Frings, Bader, and Spence (2008) used a variant of the negative priming paradigm to investigate the effect of previously presented to-be-ignored information on the speed of processing of subsequently presented tactile targets. In the typical negative priming paradigm, representing an ignored distractor stimulus as the target on the following trial leads to a cost in terms of RTs and/or error rates, thereby indicating that selection is achieved in part by the inhibiting of distractor stimuli. Frings and his colleagues reported significant costs in terms of the speed at which their participants were able to respond to a vibratory pattern presented on one hand when a previously ignored vibrotactile stimulus constituted the target on the next trial. Frings et al. concluded that the ignoring of tactile stimulus representations affected the subsequent process of selection in the participants (see also Frings, Amendt, & Spence, 2011; Frings & Spence, 2011).

It is worth noting here that Frings and his colleagues only asked their participants to ignore the tactile distractors, but this does not necessarily imply that information regarding these stimuli were not coded explicitly or that they necessarily didn't have access to participants' awareness. That is, this method does not directly test the participants' awareness of the to-be-ignored information. As a consequence, further studies will need to be carried out on neurologically normal

participants in order to investigate the nature of the representations involved in the implicit processing of tactile stimuli.

The results of the experiments reported in this section suggest that the storage of tactile information can occur despite a person's lack of awareness of that information (thus supporting the existence of implicit memory for tactile information). However, this section has also highlighted the fact that very little research has, as yet, been directed toward this important topic. As a consequence the question regarding the code used for the storage of this information remains partially unanswered.

5.7 The neural correlates of tactile memory: A modular architecture?

In this section, we review those studies that have directly addressed the neurological substrates of the different components of our tactile memory system. The results of these studies highlight the fact that tactile memories are supported by a complex neural system comprising both unimodal and multisensory/amodal processing structures. Moreover, similar to what has been reported previously for the storage of visual inputs, different characteristics of tactile stimuli are processed in different subcomponents of this network.

Our understanding of the neural correlates and topographic organization of tactile working memory has grown rapidly over the last two decades (e.g., see Bonda, Petrides, & Evans, 1996; Harris, Harris, & Diamond, 2001; Kaas, van Mier, Visser, & Goebel, 2013; Mahrer & Miles, 2002; Ohara, Lenz, & Zhou, 2006; Pasternak & Greenlee, 2005; Ricciardi, Bonino, Gentili, Sani, Pietrini, & Vecchi, 2006; Romo & Salinas, 2003; Savini, Brunetti, Babiloni, & Ferretti, 2012; see Burton & Sinclair, 2000, for a review). For example, in one particularly elegant study, Harris et al. used psychophysical testing procedures in order to investigate the topography of tactile working memory in adult humans. The participants in this study had to compare the frequency of two vibrotactile stimuli, the second of which was presented at a variable interval (ranging from 0.2 to 5 seconds) after the first. The two vibrations were either presented to the same or different digits (either the homologous finger of the opposite hand, an adjacent finger of the same hand, or to a distal finger of the same hand). Harris et al. reported that when the retention interval was shorter than 1 second, participants' performance was more accurate when the vibrotactile stimuli were presented to the same finger than when they were presented to different fingers (with participants' performance deteriorating as the distance between the two stimulated fingers increased). By contrast, for intervals of 1–2 seconds, the participants performed equally well no matter whether they had to compare vibrations presented to the same finger or to the homologous finger on the other hand (cf. Röder, Spence, & Rösler, 2002).

On the basis of such findings, Harris et al. (2001) went on to conclude that tactile working memory resides within a topographically arranged framework in the human brain. However, while it appears that tactile memories are organized somatotopically, closely following the organization of SI (where areas close on the body surface are also found close together on the cortical surface; see Figure 5.2; e.g., Narici, Modena, Opsomer, Pizzella, Romani, Torrioli, et al., 1991; Penfield & Boldrey, 1937; Penfield & Rasmussen, 1950) within the first few seconds of stimulus presentation, at longer intervals, tactile memories appear to be organized bilaterally (e.g., stimuli are stored relatively independently of the actual side of the body on which they happen to have been presented). In the latter case, therefore, people's memories of tactile stimuli might be stored at the level of secondary somatosensory cortices (SII) where neurons with bilateral receptive fields have previously been documented (e.g., Iwamura, Iriki, & Tanaka, 1994).

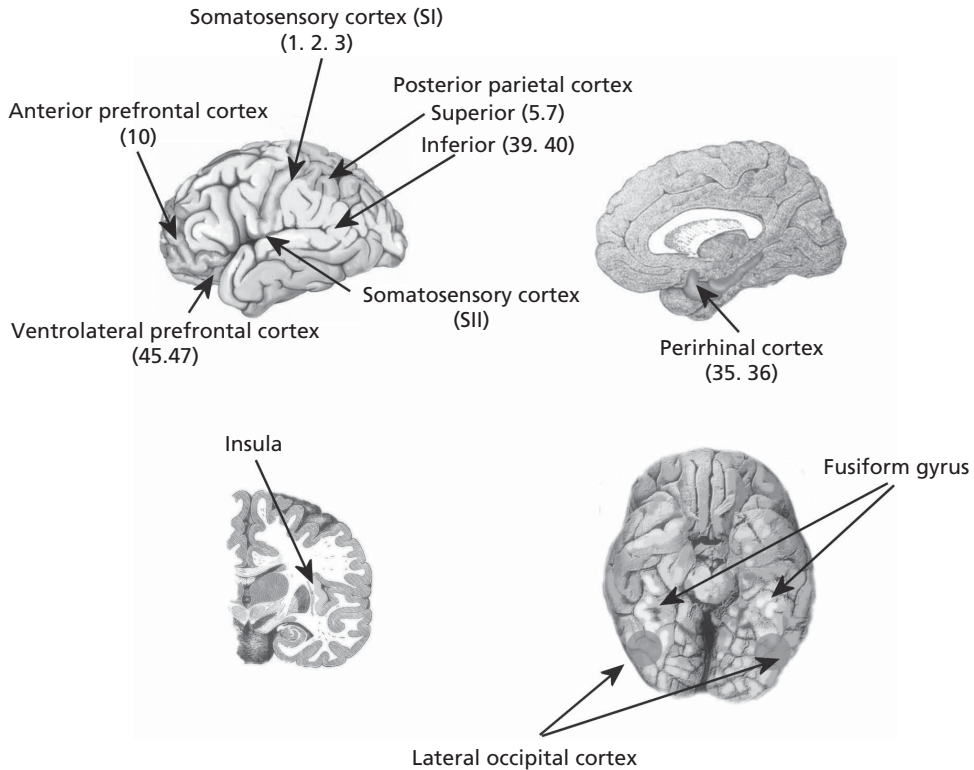


Fig. 5.2 Representation of the brain areas involved in the storage and retrieval of tactile information based on the extant literature on tactile/haptic memory reviewed here. The numbers of the corresponding Brodmann areas are also reported. Anterior prefrontal cortex: working memory, retrieval of tactile information (e.g., Kostopoulos et al., 2007); somatosensory cortex (SI): tactile sensory memory, working memory (e.g., Harris et al., 2001); somatosensory cortex (SII): retention of tactile stimuli for a few seconds after stimulus presentation (e.g., Deco et al., 2007; Hernandez et al., 2000); posterior parietal cortex: working memory, spatial attributes of tactile stimuli, short-term retention, haptic object recognition (e.g., Bonda et al., 1996; Caselli, 1993; Reed & Caselli, 1994; Reed et al., 1996); ventrolateral prefrontal cortex: retrieval of tactile information (e.g., Kostopoulos et al., 2007); perirhinal cortex: long-term storage of haptically explored stimuli (e.g., Bonda et al., 1996); insula: long-term storage of haptically explored stimuli (e.g., Bonda et al., 1996); lateral occipital complex: representation of haptically explored objects (e.g., James et al., 2002); fusiform gyrus: haptic recognition of faces (e.g., Lederman et al., 2007).

One of the questions that have driven much of the research in this area in recent years relates to the locus of tactile memories in the brain. More specifically, it is still a matter of some debate as to whether certain brain areas are specifically dedicated to the storage of tactile information or whether instead tactile memories are stored in the very same areas that process the incoming tactile information in the first place (see Pasternak & Greenlee, 2005, on this point).

Physiological studies have directly investigated the neural activity arising in the primary and secondary cortical areas (SI and SII) during the delayed discrimination of vibrotactile stimuli presented to the fingertips (e.g., Deco, Scarano, & Soto-Faraco, 2007; Hernandez, Zainos, & Romo,

2000; Romo & Salinas, 2003; see also Pasternak & Greenlee, 2005, for a review). For instance, Hernandez et al. demonstrated the existence of neurons in SII that exhibit delayed (or prolonged) activity (i.e., neurons that continued to fire after the removal of the eliciting stimulus and during the retention interval) that were correlated with the retention of the tactile stimuli that had been presented. By contrast, no such neurons were found in SI (though see Koch & Fuster, 1989; Zhou & Fuster, 1996, for contrasting results). These data therefore suggest that tactile working memory is organized into neural systems that include the very same sensory areas that are responsible for carrying out the early stages of the processing of the to-be-remembered information (note that a similar organization has also been suggested to account for the short-term memory of both visual and auditory stimuli as well; e.g., Pasternak & Greenlee, 2005).

The neural correlates of tactile working memory have also been studied in humans using functional neuroimaging techniques. For example, the participants in a study by Ricciardi et al. (2006) had to compare successively presented 2D and 3D tactile matrices while the cortical activity that was correlated with the retention and recognition of that information was measured. Interestingly, the researchers also compared a tactile with a visual working memory task using exactly the same experimental procedures. The results of their fMRI study indicated that similar frontoparietal networks were recruited during spatial working memory tasks in both the tactile and visual modalities. This network comprised the posterior parietal cortex, the dorsolateral prefrontal cortex, and the anterior cingulate cortex. Tactile (as compared to visual) memories appeared to rely on specific posterior areas involving the somatosensory cortex, but also on more anterior areas such as the middle and anterior prefrontal cortex (see also Kostopoulos, Albanese, & Petrides, 2007, for the involvement of the midventrolateral region of the prefrontal cortex in the controlled processing necessary to retrieve specific tactile information).

Following on from these findings, Ricciardi et al. (2006) went on to suggest that common cerebral regions may subserve the generation of higher order representations involved in working memory for both visual and tactile information (leading to the idea of the supramodal organization of memory representations in the brain). Moreover, Ricciardi et al.'s data is also consistent with the claim that the retention of tactile information seems to be, at least in part, related to the functioning of the same neural systems that have been shown to process that information on the input side (i.e., the somatosensory cortex and posterior regions of the brain; see Chapter 2).

Interestingly, multisensory (visuotactile) forms of memory (see section 5.3 on the interactions between visual and tactile memory) have also been studied by means of single-cell neurophysiological recordings. By means of the use of such procedures, researchers have been able to record the signal generated by individual neurons while an animal performs a specific task (e.g., storing, retaining, or recalling a particular piece of information). For example, Zhou and Fuster (1997) recorded the single-unit discharge of neurons located in the anterior parietal cortex (including those areas representing the hand) of monkeys performing a visuohaptic delayed matching-to-sample task. That is, the monkeys had to make a choice (between two tactile objects) after a delay and following the presentation of a visual cue. In that case, the monkey had to retain the association between the cue and the tactile stimulus to be chosen for the duration of the delay period.

Zhou and Fuster (1997) found that certain cells in the anterior parietal cortex of the monkey's brain changed the frequency of their firing (i.e., the number of neural signals delivered by one neuron to another in a given unit of time) during the presentation of a visual cue. Moreover, a number of the units showed sustained activation (neural activation that was also present when the eliciting stimulus disappeared) during the delay period. The authors concluded that the neurons in the somatosensory cortex were reacting to visual stimuli that had been behaviorally associated with

tactile information. The authors also suggested that certain of these neurons might be involved in the short-term active memory for visual and tactile stimuli and might, therefore, form part of the brain's crossmodal memory networks.

The neural correlates of the memory for *haptically explored objects* in humans has been investigated by Bonda et al. (1996). These researchers measured the regional cerebral blood flow in people's brains (by means of positron emission tomography; PET) as they were performing tasks involving different tactual memory tasks. In one of their experimental tasks, the participants had to explore nonsense shapes and match each of them with a previously learned set of stimuli (after a delay of a few minutes). This task was thought to require a constant reference to long-term memory. In the other experimental task, the participants had to judge the recent recurrence of shapes during the scanning period (a task that was hypothesized to involve a shorter-term form of memory).

Bonda et al. (1996) showed that the two experimental tasks requiring memory (as compared to control tasks where no information storage was of the information was required) resulted in a significant increase in activation within the posteroventral insula and the central opercular regions of the brain. Moreover, the task requiring recall from long-term memory gave rise to changes of cerebral blood flow in the perirhinal cortex instead. On the basis of such findings, Bonda et al. went on to claim that a ventrally directed parietoinsular pathway, leading to the posteroventral insula and the perirhinal cortex, might constitute a system by which the long-term representation of tactual experiences are formed, integrated and stored in the brain (see also Burton & Sinclair, 2000).

Confirmation of the involvement of the insular cortex in the tactile memory for objects has also emerged from subsequent neuroimaging research. Specifically, Reed et al. (2004) observed insular activation when their participants performed a tactile object recognition task as compared to a condition in which they were required to palpate meaningless shapes instead. Once again, it is worth noting that the network involved in the long-term storage of tactile information might be, at least in part, shared between different sensory modalities rather than being modality-specific. The results of several neuroimaging studies certainly appear to support such a claim. Specifically, Davies, Graham, Xuereb, Williams, and Hodges (2004) observed a significant change in the activation of the perirhinal cortex when their participants had to retain verbally presented information. Similarly, brain-damaged patients with lesions to the left insular cortex have been reported to exhibit impairments in their verbal long-term memory abilities (e.g., Manes, Springer, Jorge, & Robinson, 1999). Finally, Pietrini and colleagues (2004) reported that the visual and tactile recognition of man-made objects evoked category-related patterns of response in a ventral extrastriate visual area in the inferior temporal gyrus that were correlated across sensory modality, suggesting the existence of multisensory object representations (see also James et al., 2002; Kassuba, Klinge, Holig, Menz, Ptito, Roder, & Siebner, 2011; Merabet et al., 2008; Pascual-Leone & Hamilton, 2001; Sathian, 2005; Sathian, Prather, & Zhang, 2004; see also Parker & Easton, 2004). These data should surely be considered before drawing any conclusions with regard to the specificity of the neural substrates supporting our memory for haptically explored objects.

Further evidence regarding the brain areas involved in the storage of tactile object representations has emerged from the study of brain-damaged patients. In particular, it has been shown that patients suffering from tactile agnosia (a neural disorder caused by brain lesions affecting people's ability to recognize an object only by means of touch despite having relatively preserved primary and discriminative somesthetic perception; e.g., Reed, Caselli, & Farah, 1996) tend to have lesions that affect the insula, the retroinsular cortex, and the posterior parietal cortex (e.g., Caselli, 1993;

Reed & Caselli, 1994; Reed et al., 1996). Neuroimaging studies have also demonstrated that the anterior part of the intraparietal sulcus is involved in both the tactile and visual representation of objects (e.g., Grefkes et al., 2002).

Finally, Feinberg, Rothi, and Heilman (1986) have reported a case of multisensory (visual and tactile) agnosia following a lesion of the occipito-temporal cortex of the left hemisphere, suggesting that common neural structures may subserve the representations of visual and tactile aspects of objects. However, the fact that a double dissociation between visual and tactile agnosia was also reported (Reed et al., 1996), would appear most consistent with the suggestion that both unisensory and amodal/multisensory object representations may be maintained in different areas of the brain.

Stoeckel et al. (2004) conducted an event-related fMRI to investigate the lateralization of such a network for the representation of tactile objects. The researchers found that the activation of the right superior parietal areas was associated with the processing and encoding of kinesthetic information (in a task involving the sequential pairwise tactile discrimination of rectangular 3D solids), whereas the maintenance of tactile information for subsequent object discrimination resulted in the activation of left superior parietal areas instead. This result suggests that while right hemisphere structures may be involved in the processing and encoding of the characteristics of haptically explored objects (perhaps also via the processing of spatial information regarding the object's parts), the actual storage of object representations predominantly involves left hemisphere structures instead. Interestingly, neuropsychological syndromes (such as visual agnosia) leading to the failure to recognize visually presented objects also involve lesions of the left hemisphere (although in temporo-occipital areas; see Farah, 1990, for a review). By contrast, lesions of the right parietal area may lead to a lack of awareness for spatial information in more than one sensory modality (e.g., Vallar, 2001; see also Chapter 4).

In conclusion, the neuroimaging and neuropsychological studies that have been conducted in humans, and the neuroanatomical studies that have been conducted in monkeys, appear to show that the storage of tactile information seems to rely on SII, the posterior parietal cortex, the insula and the frontal cortex for short-term retention and to structures of the medial temporal lobe (such as the perirhinal cortex) for long-term stimulus encoding (e.g., Bonda et al., 1996; Burton & Sinclair, 2000). This network, where retention seems to be distributed over a number of distinct structures (comprising those involved in the very processing of the stimuli), rather than encapsulated in specific brain areas, contributes to the storage of different aspects of haptically presented information (see Figure 5.2). The latter claim might lead to the suggestion that different cognitive limitations (e.g., in terms of the duration of the trace and the amount of information that can be stored) might be expected for different aspects of the to-be-remembered tactile stimuli.

5.7.1 What versus where: A dual path system for the representation of touch?

The difference between the neural correlates of haptic memory for spatial positions and the memory for 3D objects was addressed directly by Stock et al. (2004). Their participants had to learn associations between cues (auditorily presented words) and target stimuli. The targets consisted of haptically explored 3D objects or haptically explored locations in 3D space. In the retrieval test, the participants heard two cue words and had to decide whether or not they were associated with the same target or not. Stock et al. measured the blood oxygen level-dependent (BOLD) responses of their participants during the retrieval task. The results showed that the retrieval of haptically

encoded objects activated, among other areas, the secondary somatosensory cortex (SII), the insula, and the posterior parietal cortex (PPC), whereas the retrieval of haptically encoded spatial positions activated, among others, SII and the PPC, but interestingly, not the insula.

Macaluso and Driver (2003) also observed activation in the PPC following the presentation of both spatially organized visual and tactile stimuli (i.e., lights or vibrations presented from the left or right side of the body/visual field), suggesting that this region has multisensory features and may be engaged in the short-term maintenance of spatial information irrespective of the input modality (see also Ricciardi et al., 2006). Evidence from different research domains therefore appears to converge on the conclusion that distinct areas of the parietal cortex, in particular of the right hemisphere, subserve the maintenance of multisensorially derived representations of space and likely contribute to the awareness of tactile information (see Chapter 4). Moreover, on the basis of the data obtained from the study of those patients affected by unilateral neglect, it has been suggested that the right hemisphere (and, in particular, the parietal areas), might support the representation of both sides of the body (e.g., Bottini, Paulesu, Gandola, Loffredo, Scarpa, Sterzi, et al., 2005). This part of the brain might therefore be the perfect candidate for supporting the storage (together with the processing) of the spatial aspects of those stimuli that are presented across/close to the body surface, regardless of their sensory modality (see Vallar, 2007; cf. Gallace et al., 2008b).

Given that the processing of tactile stimuli under conditions of active exploration implies the presence of voluntary movements, one should not fail to consider the connections between the neural systems involved in the processing of movement and of tactile information in the brain. In particular, a number of studies have now changed the functional view of PPC from one of higher-order somatosensory and visual processing to part of a more complex system of interconnected parietal and frontal circuits, that has the function of coupling perceptions to action for accomplishing specific goals (e.g., Buneo & Andersen, 2006; Fogassi & Luppino, 2005; Gardner, Babu, Reitzen, Ghosh, Brown, Chen, Hall, et al., 2007; see Andersen & Buneo, 2002, for a review). Following on from these observations, one may question the extent to which the neural representations of tactile information are linked to the representations of actions in the brain. A strong connection between multisensory (visuotactile) and motor networks might allow, under specific conditions (i.e., task demands), a quicker pre-activation of the neural representations relative to the appropriate action involved in manipulating or using a particular object whenever the representation of such an object is activated by tactile and/or visual inputs (cf. Jeannerod, Arbib, Rizzolatti, & Sakata, 1995).

In conclusion, the studies reviewed in this section demonstrate that the systems involved in tactile memory can be distinguished into different neuroanatomically distinct components as a function of the properties of the stimuli to be represented. In particular, while spatial information would appear to be stored in SII and PPC, the storage of information regarding haptically explored objects appears to require the activation of the insula as well. This distinction between the memory for position (where) and the memory for identity (what) of tactile stimuli seems to be similar to that reported previously for the processing and storage of visual stimuli and to that reported for the processing of information regarding different sensory modalities (e.g., Chan & Newell, 2008; De Santis, Spierer, Clarke & Murray, 2007; Haxby et al., 2001; Ishai et al., 2000; Khader et al., 2005; Renier, Anurova, De Volder, Carlson, VanMeter, & Rauschecker, 2009; see also Reed, Klatzky, & Halgren, 2005, for neuroimaging evidence supporting a distinction between where and what pathways in the neural systems underlying the processing of tactile sensory information). On the basis of these considerations, one might reasonably argue that a dual pathway system comprising both a ventral and a dorsal neural stream, is in charge of processing and representing different

aspects of haptically explored objects or tactile locations (e.g., Reed et al., 2005; see Dijkerman & de Haan, 2007, for a model of somatosensory processing elaborated along these lines). This dual memory system might also be, at least up to a certain point, lateralized in the human brain, with a prevalence of left hemisphere structures involved in the storage of object structural characteristics and a predominance of right hemisphere structures involved in the storage of the spatial aspects of the stimuli (e.g., Vallar, 2007). The latter claim might find further behavioral support by research investigating whether or not different durations or storage capacities for stimuli presented on the left, as compared to on the right, side of the body surface can be observed when the recollection of spatial versus identity characteristics is required by the task.

The results of this review of the literature concerning the neural correlates of tactile memory clearly converge in suggesting that the storage of tactile information occurs in the very same brain networks involved in the initial processing of this sensory information (e.g., Ricciardi et al., 2006; see also Murray et al., 1975). It should, however, be noted that this commonality of networks for perception and memory, rather than being specific to the tactile modality, might reflect a more general principle in the functioning of the central neural system, one that helps to account for our memory of tactile stimuli as well as our memory for stimuli presented in other sensory modalities (e.g., McClelland et al., 1995; Rösler & Heil, 2003). Finally, the studies summarized in this section suggest that certain brain structures responsible for the storage of visual aspects of stimuli might also be responsible for the storage of tactile information as well (e.g., Reed et al., 2004; Zhou & Fuster, 1996; see also James, James, Humphrey, & Goodale, 2005). That is, similar or shared neural networks and/or pool of neurons would seem to be responsible for the maintenance of stimuli presented from different sensory modalities. Alternatively, it might be possible that the apparent commonality of structures reported in the extant literature of visual and tactile memory is solely related to the proximity of modality-specific neural networks involved in representing and processing similar aspects of the stimuli.

5.8 Conclusions

The results of the research reviewed in this chapter highlight some of the most important characteristics and limitations of our memory for tactile information. Cognitive neuroscientists have generally tended to use the extant models of memory that have been developed for the visual and auditory modalities in order to show that different memory systems are responsible for different aspects of the storage of tactile information (see Figure 5.3 for a representation of the components and characteristics of a possible neurocognitive tactile memory system that have emerged from the literature reviewed in this chapter). At first glance, these visual and auditory models would also seem to be compatible with the organization of our memory for tactile stimuli. In particular, research has demonstrated that short-term tactile memory systems appear to be involved in the brief storage of information regarding the position and sensory qualities of tactile stimuli presented across the body surface.

Interestingly, behavioral and neuroimaging studies have demonstrated that these short-term representations tend to rely upon the very same areas of the brain that are involved in the original *processing* of tactile sensory information. That is, it does not appear as though there are encapsulated and/or separate systems for the short-term storage of tactile stimuli (e.g., Harris et al., 2001; Ricciardi et al., 2006; see also Murray et al., 1975). Along similar lines, it has also been proposed that a dual path system for the spatial and identity qualities of the stimuli might be involved in both the processing and storage of tactile/haptic information in the brain (e.g., Dijkerman & de Haan, 2007).

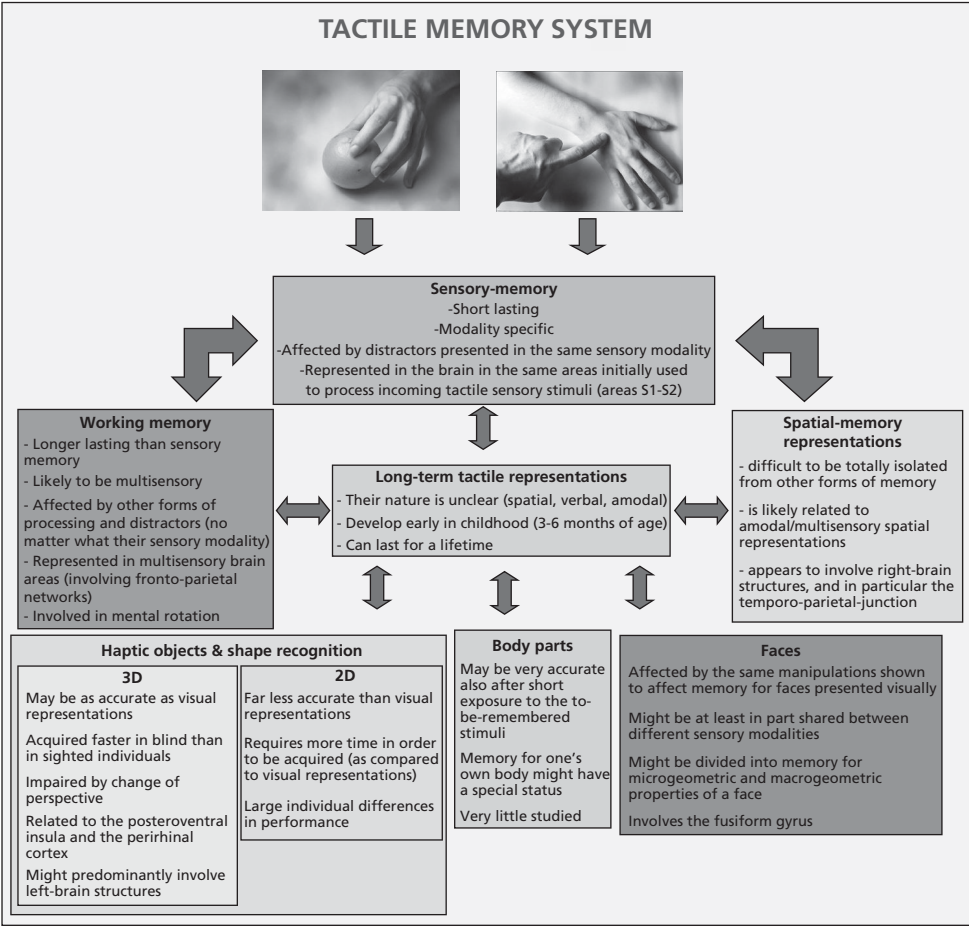


Fig. 5.3 Model representing a possible neurocognitive system for the retention of tactile information.

Researchers have also highlighted the presence of longer-term representations of tactile information. These representations are generally used to recognize and remember the qualities and spatial position of the objects/stimuli that we manipulate (e.g., the softness of your teddy-bear; the size and feeling of a coin in your pocket; the positions and shapes of your door keys in a dark room or in your handbag; the feeling of a swollen lymph gland by a physician). It is important to note, however, that the nature of these representations still seems to be a matter of some debate. Indeed, while certain empirical data would appear to suggest that these representations are, at least in part, verbal (and shared between different sensory modalities), other research supports the view that they are actually “spatial” in nature (and not necessarily the same for all the senses).

On the basis of the literature reviewed here, it would appear that the approach of using the framework provided by previous studies of visual and auditory memory in order to try and understand tactile memory might also have certain limitations. In particular, the fact that under certain circumstances (such as when real objects are presented) tactile information can be coded by means of alternative forms of representation (visual, spatial, and verbal/semantic) seems to make the study of tactile memory more complex than that of visual and auditory memory. (Note that it would seem unlikely that visual memories would be translated into tactile codes, perhaps

making their study less complex.) However, it should also be noted that the role of alternative forms of representation might have been, at least in part, underestimated in the extant literatures on visual and auditory memory. In particular, many aspects of our memory can be related to the spatial (and consequently amodal/multisensory) processing and storage of the stimuli (see also Spence & Deroy, 2013). For example, it has been shown that even for “peripheral” visual iconic memory, the observed decay involves the loss of “spatial” information about the items, rather than a loss of information concerning the identity of the items (e.g., Mewhort et al., 1984; Mewhort & Leppmann, 1985; Townsend, 1973). A similar line of reasoning can be applied to the role of verbal/semantic representations in the long-term storage of visually presented objects (e.g., Davies et al., 2004; Manes et al., 1999).

The results of the majority of the literature reported in this chapter is consistent with the claim that interactions between the information presented via different sensory modalities occurs at a number of different stages of processing leading to the storage of information in the brain. The suggestion has also been made that when people need to use their memory actively (i.e., during working memory tasks), common representations (with common neural substrates) may subserve the storage of tactile as well as visual and perhaps also auditory stimuli (e.g., Ricciardi et al., 2006).

Comparison of those studies that have investigated different modalities of stimulus presentation suggests that haptic exploration results in better memory than passive tactile stimulation of the body surface (cf. Gallace et al., 2008b). Similarly, our retention of 3D objects seems to be more effective than the retention of 2D raised lines drawings. The results of the developmental studies reviewed here clearly show that tactile memory systems emerge very early in human development (as early as 2 months after birth; see Lhote & Streri, 1998; see also Streri, 2012, for a review), even when our visual system has not yet become fully effective. In conclusion, this review has shown that tactile memory represents an important, if currently under-investigated, topic that needs to be further addressed by cognitive neuroscientists and psychologists.

The review of the literature that has been presented in this chapter has also highlighted the importance of the study of tactile memory from a more holistic point of view. In particular, it has been shown that more research should be dedicated to studying the role of multisensory processing in the encoding, storage, and retrieval of information in the brain (cf. Lehmann & Murray, 2005). That is, in the years to come, researchers should address the question of what specific aspects of our memory systems (and which supporting neural structures) are modality-specific and what is instead multisensory or amodal. Finally, given that different tactile tasks may require different demands in term of bodily movements, it would be of interest to study how the neural systems that support different forms of tactile memory relate to the system involved in moving our body in space.

In Chapter 6 we will describe how the deployment of attention may affect our ability to process tactile information.

Acknowledgments

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Chapter 6

Tactile attention

The doctrine of attention is the nerve of the whole psychological system, and . . . as men judge of it, so shall they be judged before the general tribunal of psychology.

(*Titchener, 1908, p. 173*)

6.1 Introduction

Attention refers to those neurocognitive processes that allow for the *selective* processing of incoming sensory stimuli (Spence, 2010a, b). Mechanisms of selective attention help us to prioritize those stimuli that are most relevant to achieving our current goals and/or to performing a given task. The term “attention” is used here to describe those processes that give rise to a temporary change (often enhancement) in signal processing.¹ This change will often be manifest in only a subset of the stimuli presented (or available) at any time.

After what we have seen in the previous chapters, it should come as little surprise that the majority of selective attention research over the past 50 years or so has focused on the processing of unimodal auditory and visual information (e.g., see Driver, 2001; Pashler, 1998, for reviews). Far fewer studies have attempted to investigate the effects of attention on the processing of information in other sensory modalities, such as touch (though see Spence, 2002a). It is also perhaps unsurprising, then, that the majority of theoretical insights concerning the mechanisms and principles governing selective attention have been developed on the basis of unimodal visual and auditory attention research (see Gallace & Spence, 2010b). That said, the last decade has seen a rapid growth of research on the topic of tactile (and multisensory) attention (e.g., Anderson, Ferguson, Lopez-Larson, & Yurgelun-Todd, 2010; Jones & Forster, 2012; Macaluso 2012; Spence, 2002a, 2010b; Spence & Driver, 2004). What is more, recent developments in cognitive neuroscience mean that we now know far more about the neural mechanisms underlying tactile attention than ever before. Research on the topic of tactile attention is, we believe, particularly important at the present time, given its relevance to those working in the recently revived field of tactile interface design (see Chapter 9).

Over the years, many researchers have demonstrated that attention can be deployed both endogenously (i.e., voluntarily) and exogenously (i.e., as in the automatic capture of attention by an abrupt stimulus onset; e.g., Klein & Shore, 2000; Spence, Nicholls, & Driver, 2001a). Cognitive

¹ Note that a definition of attention is always necessary given that the meaning of this word has often been the object of some debate among researchers in this area, as effectively summarized by Spearman (1937, p. 133): “the word ‘attention’ quickly came to be associated by them [researchers] with a diversity of meanings that have the appearance of being more chaotic even than those of the term intelligence.”

psychologists and psychophysicists have demonstrated that attention can be directed to a particular sensory modality (e.g., Spence et al., 2001a; Spence, Shore, & Klein, 2001b), to a specific spatial location (e.g., Lakatos & Shepard, 1997b; Soto-Faraco, Ronald, & Spence, 2004), and even to a specific tactile feature or attribute (e.g., Burton, Sinclair, & McLaren, 2008; Sinclair, Kuo, & Burton, 2000). Over the last decade or so, a number of similarities between the capacity limitations affecting visual, auditory, and, more recently, tactile information processing have been revealed (see, for example, Chapters 3 and 4, for the limitations affecting the amount of information that can be processed at any one time in the tactile modality). Interestingly, however, a number of potentially important differences between the attentional limitations affecting tactile as compared to visual and auditory information processing have also been highlighted as well (e.g., Forster & Eimer, 2005). For instance, people tend to find it harder to shift their attention away from the tactile modality once it is focused there than they do to move the focus of their attention away from the auditory or visual modalities (Spence et al., 2001a, b; Turatto, Galfano, Bridgeman, & Umiltà, 2004). In this chapter, we will primarily focus on reviewing the most important recent research that has highlighted the constraints on people's ability to attend to, and process, tactile information presented passively to their skin surface (mostly on the hands, but on occasion also on the rest of the body surface). We will start by analyzing the results of those studies that have directly addressed the behavioral constraints underlying our ability to attend to tactile stimuli. Questions related to the investigation of endogenous and exogenous attention will be addressed separately. Next, the phenomenon of inhibition of return (IOR) within the tactile domain will be discussed. An important topic throughout the present chapter concerns the role of top-down control over attentional orienting and, in particular, the possibility that attentional mechanisms might be similar and/or shared across different sensory modalities. In one of the final sections (see section 6.7), the deployment of tactile attention and its limitations will be discussed not only with reference to those areas of the body with a higher sensitivity (and most studiously investigated), such as the hands, but to the whole body surface.

6.2 Touch and attention

One of the oldest questions in attention research concerns the extent to which people can selectively direct their attention toward a particular sensory modality, such as toward touch (Stone, 1926). Spence et al. (2001a) addressed this question, while ruling out a number of the confounds (in terms of response priming, criterion shifts, etc.) that had made the interpretation of previous studies on this topic somewhat unclear, in a study in which participants were presented with a random sequence of tactile, visual, and auditory targets from one of two locations on either side of fixation. The participants had to make speeded left/right spatial discrimination responses to the target stimuli regardless of the modality in which they were presented. The three target modalities were presented equiprobably in the "divided attention" blocks. Meanwhile, in the other blocks of trials, the probability of the stimuli being presented in a particular target modality (touch, audition, or vision) was increased, in order to encourage the participants to focus their attention on that modality.

The results of Spence et al.'s (2001a) study revealed that participants responded more rapidly (and somewhat more accurately) to the tactile targets in the "attend touch" blocks than in those blocks of trials where either visual or auditory targets were expected instead. These results therefore demonstrate that voluntarily (i.e., endogenously) attending to touch can facilitate a person's responses to tactile stimuli when compared to situations in which their attention was directed toward the auditory or visual modalities. Spence, Kettenman, Kobal, and McGlone (2000a) have

even reported that attending to olfaction (i.e., expecting a smell) can impair a person's ability to respond to tactile stimuli as well (cf. Förster, 2011; see also Keller, 2011; Stevenson, 2012, for recent studies of olfactory attention).

Spence, Shore, and Klein (2001b) demonstrated that the effects of selective attention to the tactile modality occur at an early perceptual level of information processing. Using an unspeeded temporal order judgment (TOJ) task, they reported that voluntarily (i.e., endogenously) attending to touch actually speeds up the "perceived" (relative) time of arrival of tactile (as compared to visual) stimuli (a phenomenon known as "prior entry"; Titchener, 1908; see also Spence & Parise, 2010, for a review). In particular, Spence et al. found that a visual stimulus had to be presented significantly earlier in time relative to a tactile stimulus in order for the two stimuli to be perceived as simultaneous (or rather, for participants to make light-first and touch-first responses equally often) when their attention was directed endogenously toward the tactile modality than when their attention was directed toward the visual modality instead.

Subsequently, Vibell, Klinge, Zampini, Spence, and Nobre (2007) reported a combined behavioral and event-related potential study of this visuotactile prior entry effect. They demonstrated that a small (but significant) slowing of the early neural processing of visual stimuli (in particular, the visually evoked N1 and P1 components) occurred when participants directed their attention endogenously toward touch as compared to when the same participants directed their attention toward the visual modality instead. What is more, the magnitude of this latency shift in the early neural responses to visual stimuli (specifically the P1 and P3 components) correlated with the magnitude of the prior entry effect reported behaviorally. That is, those participants who exhibited a larger prior entry effect (as assessed psychophysically) also tended to show a larger latency shift in their ERP data. These results therefore provide some of the first direct electrophysiological evidence that attending to a particular sensory modality, such as touch, really does speed up the relative perceptual time of arrival of sensory stimuli in that modality. Vibell et al.'s results also provide an insight into when and (to a lesser degree) where such attentional effects occur in the human brain. In fact, a growing number of neuroimaging studies have now been published demonstrating that the selection of tactile information can occur at very early stages of neural processing, such as in the somatosensory regions of the parietal cortex (i.e., in S1 and S2, see Burton, Abend, MacLeod, Sinclair, Snyder & Raichle, 1999; Chapman & Meftah, 2005; Gillmeister, Sambo, & Forster, 2010; Sterr, Shen, Zaman, Roberts, & Szameitat, 2007). To date, however, there has been far less research on the question of whether or not attention can also be drawn exogenously (i.e., in a stimulus-driven manner) toward a particular sensory modality. One of the few studies to have addressed this issue directly (with respect to the tactile modality) was reported by Turatto et al. (2004). Participants in that study were presented with auditory, visual, and tactile targets from the same central spatial location. They had to make speeded discrimination responses regarding the elevation of the visual and tactile stimuli, and the frequency of the auditory stimuli. A non-informative cue was presented from the same central location shortly before the onset of each target (at stimulus onset asynchronies—SOAs—of 150, 600, and 1000 ms). The results revealed that at the shortest SOA, participants' responses to the tactile targets were faster following a tactile pre-cue than following either an auditory or visual pre-cue. The presentation of the tactile cues also resulted in a significant slowing of their responses to the visual and auditory stimuli (as compared to when these stimuli were preceded by a cue in the same sensory modality). These results therefore provide convincing empirical evidence that attention can be directed in a stimulus-driven (or exogenous) manner toward a particular sensory modality (see also Spence et al., 2001a).

6.3 Endogenous spatial attention

Researchers studying the topic of *spatial* (rather than non-spatial) attention have also emphasized a distinction between endogenous and exogenous orienting (e.g., Klein, 2009; Klein & Shore, 2000; see also Spence & Driver, 2004): That is, between the voluntary (or endogenous) orienting of spatial attention that is induced by advance knowledge concerning where a target is likely to occur—such as a verbal instruction to expect a tactile stimulus on the left hand; and the reflexive (or exogenous) orienting of spatial attention that is observed in response to salient, but spatially non-predictive, peripheral events—such as, for example, when a fly suddenly lands on your shoulder. Traditionally, the majority of tactile spatial attention research has focused on the behavioral and neural consequences of voluntary shifts of attention on tactile performance (see Spence, 2002a, for a review).

By now, many different studies have demonstrated that people can direct their tactile spatial attention voluntarily to a particular hand, and that this facilitates the processing of any tactile stimuli that are subsequently happen to be presented there (e.g., Bradshaw, Howard, Pierson, Phillips, & Bradshaw, 1992; Driver & Grossenbacher, 1996; Forster & Eimer, 2005; Sathian & Burton, 1991; Spence, Pavani, & Driver, 2000, 2004; Vibell, Klinge, Zampini, Spence, & Nobre, 2007; Yates & Nicholls, 2009, 2011; cf. Van Damme, Gallace, Spence, Crombez, & Moseley, 2009). Forster and Eimer have demonstrated that these spatial cuing effects consist of both a facilitation of responses to tactile stimuli presented on the cued (or attended) side and a cost associated with responding to those tactile stimuli presented on the unexpected side (although the costs in this study, as is often the case, were much larger than the benefits; see also Spence et al., 2001a). Meanwhile, Lakatos and Shepard (1997b) reported that tactile attention can be directed to different positions on the body surface, with the time taken to shift attention between two different bodily locations depending on the physical (i.e., Euclidean), rather than on the somatotopic, distance between them.

Importantly, not only can we direct our somatosensory attention toward different positions on the body, but it can also be directed toward interoceptive signals (i.e., information regarding temperature, pain, itch, muscular and visceral stimuli, hunger, and thirst that define the physiological condition of the body at a given time; e.g., Craig, 2002, 2003; see also Rief & Broadbent, 2007). Mirams, Poliakoff, Brown, and Lloyd (2012) recently studied whether interoceptive and exteroceptive attention would differentially affect the propensity for an individual to report feeling ambiguous external stimulation, consisting in this case of near-threshold tactile stimulation accompanied, in a number of the trials, by the presentation of a light (see also Brown, Brunt, Poliakoff, & Lloyd, 2010; Lloyd, Mason, Brown, & Poliakoff, 2008; McKenzie, Lloyd, Brown, Plummer, & Poliakoff, 2012; McKenzie, Poliakoff, Brown, & Lloyd, 2010; Mirams, Poliakoff, Brown, & Lloyd, 2010). Using an unspeeded signal detection task, these researchers reported that attending to interoceptive signals, namely to one's heartbeat, increased the number of tactile targets that were both correctly and incorrectly reported, as compared to a condition in which the participants did not have to attend to these internally generated signals. By contrast, when the participants had to focus their attention on an exteroceptive task (i.e., a task in which the participant has to discriminate the orientation of a grid), the number of tactile stimuli reported decreased (for both tactile present and absent trials). On the basis of these results, the authors concluded that focusing attention on internal and external events has opposite effects on people's response bias to somatosensory stimulation. Such results may well have implications for the clinical understanding of somatic disorders.

Over the last decade or so, cognitive neuroscience researchers have come a long way in terms of their understanding of the neural mechanisms responsible for the voluntary orienting of an individual's tactile *spatial* attention (e.g., Forster, Sambo, & Pavone, 2009; Gherri, & Forster, 2012a, b; Kida, Inui, Wasaka, Akatsuka, Tanaka, & Kakigi, 2007; Oliveri, Rossini, Filippi, Traversa, Cicinelli, Palmieri, Pasqualetti, & Caltagirone, 2000). Neuroimaging research has highlighted the importance of the parietal cortex (e.g., Macaluso & Driver, 2004; though see Chambers, Stokes, & Mattingley, 2004), as well as the early somatosensory cortex (e.g., SI, SII, and SIII; see Burton & Sinclair, 2000; Sambo & Forster, 2011) in the endogenous orienting of tactile *spatial* attention. However, very few research groups have attempted to look at the reflexive (as opposed to voluntary) orienting of tactile attention, and it is to this rapidly growing area of research that we turn next.

6.4 Exogenous spatial attention

Spence and McGlone (2001) were probably the first to demonstrate that people's responses to tactile stimuli can also be facilitated by the exogenous (i.e., reflexive) orienting of their spatial attention to a particular position (or part of their body). The participants in their study made speeded elevation discrimination responses (by lifting their toes or heel from one of a pair of footpedals situated under their right foot) to brief vibrotactile targets presented to the top (i.e., under one of the participant's index fingers) or bottom (i.e., under one of their thumbs) of one of two foam cubes (with one cube held in either hand). A vibrotactile cue (consisting of the activation of both stimulators on one or other cube for 20 ms) was presented randomly from either side, shortly before the onset of the target stimulus (at SOAs of 200, 300, or 400 ms). Even though the side on which the tactile cue was presented was completely spatially non-predictive with respect to the side on which the vibrotactile target would subsequently appear, the participants in this study nevertheless responded significantly more rapidly at all three SOAs (and somewhat more accurately overall), on those trials where the target was presented on the same, rather than opposite, side as the tactile cue. Spence and McGlone argued that, in the absence of any other form of stimulation, tactile spatial attention is automatically drawn toward the location of any sudden tactile event occurring on the body surface.

Researchers have also demonstrated that people's responses to vibrotactile targets presented to either hand can be facilitated by the prior presentation of an auditory or visual stimulus (i.e., cue) from close to the target hand as well (see Kennett, Eimer, Spence, & Driver, 2001; Kennett, Spence, & Driver, 2002; Spence, Nicholls, Gillespie, & Driver, 1998; cf. Gillmeister & Forster, 2010), no matter whether the participants' hands were placed in a crossed or uncrossed posture (see Spence, McDonald, & Driver, 2004, for a review). These spatial cuing effects have been shown to affect the performance of participants in both spatial (i.e., elevation) and non-spatial (i.e., continuous vs. pulsed) discrimination tasks (cf. Spence et al., 2004). It is important to mention here that the majority of the earlier crossmodal studies of exogenous spatial attention simply compared their participants' speeded tactile discrimination performance as a function of whether the visual (or auditory) cue was presented from the same versus opposite side of fixation. Only subsequently have researchers demonstrated the spatial specificity of these effects (e.g., Chong & Mattingley, 2000; Mohebbi, Gray, & Tan, 2009; see also Eimer & Van Velzen, 2005, for the endogenous case). In fact, Spence et al. (2004) have argued that the spatial distribution of any cuing effects that are observed following the presentation of a peripheral non-predictive cue will depend on the localizability of the cue stimulus itself (with tactile and auditory cues typically giving rise to more spatially diffuse cuing effects than those seen following the presentation of a visual cue; Chong & Mattingley, 2000; see Figure 6.1).

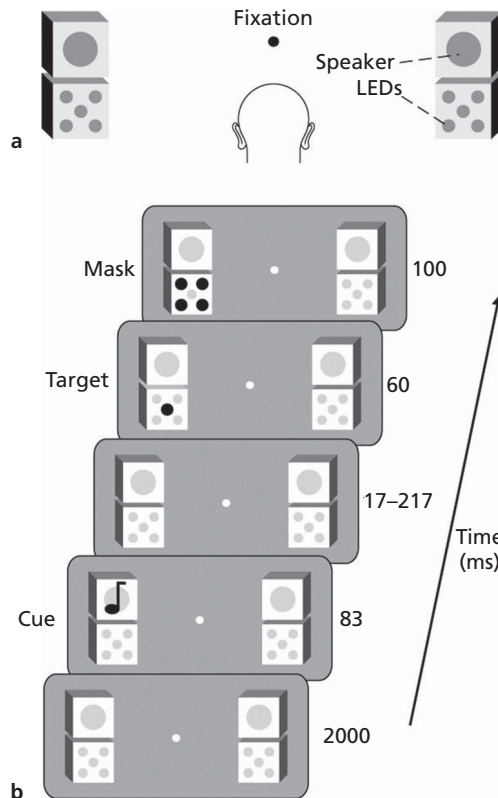


Fig. 6.1 (a) Schematic illustration of a possible stimulus sequence within a trial from McDonald et al.'s (2000) audiovisual cuing study that measured visual perceptual sensitivity. (b) A brief tone cue was presented from either the left or right at the start of each trial. This was followed a short time later by the presentation of a visual mask (consisting of the illumination of four red LEDs) on either the same side (as shown here) or on the opposite side. On a random 50% of either type of trial, a visual target (consisting of a green target LED in the center of the array) was presented briefly on the same side as the visual mask and directly before it. Participants were required to make an unspeeded judgment concerning the presence or absence of the brief, masked visual target. Reproduced from *Nature*, 407 (6806), John J. McDonald, Wolfgang A. Teder-Salejari and Steven A. Hillyard, Involuntary orienting to sound improves visual perception, pp. 906–908, © 2000, Nature Publishing Group.

Poliakoff, Miles, Li, and Blanchette (2007) have reported that the nature of the visual stimulus can modulate the size of the tactile spatial cuing effect. These researchers used pictures of snakes, spiders, flowers, and mushrooms as the non-informative visual cues (rather than the flashing of an LED which has typically constituted the visual stimulus in the majority of previous crossmodal attention studies). One of the four pictures was randomly presented on either the left or right side of a flat-screen monitor on each trial. A vibrotactile target requiring a speeded frequency discrimination (high vs. low) response was presented to one of the participant's hands (one placed directly behind either side of the screen), 250, 500, or 1000 ms later. Even though the side of the visual cue was (once again) non-predictive with respect to the target side, the threatening visual image of a snake nevertheless elicited a significantly larger crossmodal cuing effect at the shortest SOA than did any of the other three visual images. What's more, the magnitude of this facilitatory

effect correlated with participants' self-reported fear of snakes and spiders. Poliakoff et al.'s results therefore show that the threat value of a visual stimulus can modulate the crossmodal capture of tactile spatial attention by visual stimuli.

In a similar study, Van Damme, Gallace, Spence, Crombez, and Moseley (2009) had their participants make TOJs regarding pairs of tactile (or auditory) stimuli, one presented to either hand. A picture showing physical threat, general threat, or no threat was also presented in front of one or the other hand before the onset of the tactile stimuli. The results revealed that tactile attention was biased toward the side where the picture had been presented. Importantly, this effect was larger for pictures showing physical threat than for general threat or neutral pictures. The opposite pattern of results was observed when the participants had to make auditory TOJs instead. These results were taken to suggest that not only are visual stimuli effective in capturing a participant's tactile attention but that the effect will depend on the proximity between the visual threat and the region of the body where the stimuli are delivered. Gray and Tan (2002; experiment 2) also demonstrated that the speeded discrimination of the frequency (high vs. low) of tactile targets, presented from one of three positions along participants' forearms, can be facilitated by the approach of a neutral object (a simulated 3D visual object) toward the participant's arm (where the tactile stimulus was subsequently presented; see also Makin, Holmes, Brozzoli, Rossetti, & Farnè, 2009).

Finally, Soto-Faraco, Sinnett, Alsius, and Kingstone (2006) have demonstrated that tactile spatial attention can even be oriented to either hand following the central presentation of a cartoon drawing of a face that happens to be randomly looking toward either the left or right (i.e., to where one of the participant's hands was placed). These results represent the first demonstration of the social cuing of tactile attention (under conditions where the direction of the centrally presented eye-gaze cue was non-predictive with respect to the target side). The robustness of this spatial cuing effect was highlighted by the fact that a similar pattern of results was observed using speeded detection, speeded discrimination, and unspeeded signal detection tasks. Interestingly, Soto-Faraco et al. also found that central arrow cues (pointing to the left or right) were just as effective as the eye-gaze cues in eliciting a shift of tactile spatial attention.

6.5 The effect of postural changes on tactile attention

Many studies published over the last two decades have clearly indicated that shifts of visuospatial attention are elicited during the covert preparation of spatially directed eye or body movements (e.g., Deubel & Schneider, 1996; Deubel, Schneider, & Paprotta, 1998; Linnell, Humphreys, McIntyre, Laitinen, & Wing, 2005; Montagnini & Castet, 2007). For example, the preparation of an eye movement will result in a shift of covert attention toward the location of the saccade target. Similarly, it has also been shown that visual perception is enhanced at the locations where a body movement (i.e., a pointing) is directed (e.g., Baldauf & Deubel, 2009; Jonikaitis & Deubel, 2011). Such results indicate that attention is shifted to the target of the movement. More recently, the role of movement on the endogenous orienting of attention has also started to be investigated by using tactile stimuli. In particular, in a recent study by Gherri and Forster (2012b), the participants had to prepare an eye movement toward—or a hand movement with—the left or right hand. The kind of movement preparation was indicated by a cue followed (after 500 or 700 ms) by a tactile probe. The participants were asked to ignore all tactile events, and to respond as fast as possible to a given letter appearing on a computer monitor. The authors recorded the somatosensory evoked potentials elicited by the presentation of the irrelevant tactile stimulus. They found that hand movements exerted a larger modulation of tactile processing than eye movements, indicating stronger attentional modulations for the modality of the effector's sensory organ. That is, executing a given

movement toward a certain part of space drives our attention toward that region, thus affecting tactile processing of the stimuli occurring there.

A recent fMRI study by Jackson, Parkinson, Pears, and Nam (2011) investigated those areas involved in the modulation of tactile exogenous attention by body movements. Their behavioral data showed that a somatosensory stimulus delivered to a hand that has been prepared for movement is perceived to have occurred later than when that same stimulus is delivered to a nonmoving hand. This result doesn't seem to support the idea that movement intention leads to enhanced perceptual processing at the target of a movement, as mediated by shifts in attention. By contrast, such result indicates that it takes longer for a tactile stimulus to be detected when it is delivered to a moving limb and may correspond to a sort of sensory suppression effort by the movement intention on tactile processing (e.g., Chapman & Beauchamp, 2006; see Chapter 9, for a discussion of sensory suppression during moment execution). The brain imaging results revealed that there were significantly reduced BOLD responses within the parietal operculum and the insula following the tactile stimulus presented on the hand that was prepared for movement, compared to when an identical stimulus was delivered to a non-moving hand. That is, body movement is likely to affect selection and processing of tactile information by means of higher-order areas in the brain. However, the result of Jackson et al. also highlight the fact that if one wants to study the role of body movement in the selection of tactile stimuli, the phenomenon of sensory suppression also needs to be taken into account.

6.6 Inhibition of return

As the length of the interval between the presentation of a non-predictive spatial cue and the target stimulus is increased in traditional spatial cuing studies (typically beyond 300 ms or so; see Klein, 2000), the facilitatory effect on target detection/discrimination responses normally seen at the cued location is often replaced by an inhibitory after-effect, known as "inhibition of return" (IOR; e.g., see Cohen, Bolanowski, & Verrillo, 2005; Miles, Poliakoff, & Brown, 2008; Poliakoff, O'Boyle, Moore, McGlone, Cody, & Spence, 2003; Poliakoff, Spence, O'Boyle, McGlone, & Cody, 2002; Röder, Spence, & Rösler, 2000; Spence, Lloyd, McGlone, Nicholls, & Driver, 2000b). Many researchers have argued that this inhibitory aftereffect may help to prevent attention from returning to a previously attended location (thus, presumably, enhancing the efficiency of visual search; e.g., see Klein & MacInnes, 1998; Posner, Rafal, Choate, & Vaughan, 1985). Once again, the slowing of a participant's responses (normally detection responses) to tactile targets presented at longer SOAs has now been shown to occur after the presentation of auditory, visual, and vibrotactile cues (Spence et al., 2000b; Tassinari & Campara, 1996). What is more, these IOR effects can last for several seconds after the presentation of a tactile cue (Cohen et al., 2005), and can affect the processing of electrocutaneous tactile stimuli presented to other parts of the body (such as on the shoulders) as well (see Tassinari & Campara, 1996). However, while the exogenous orienting of spatial attention has been demonstrated to follow a participant's hands through space (thus showing that crossmodal links in spatial attention are updated following posture change; see Spence et al., 2004, for a review), no such postural updating has been demonstrated for the case of IOR (e.g., see Driver & Spence, 1998; Röder, Spence, & Rösler, 2002).

6.7 The top-down modulation of exogenous spatial orienting

It is striking to note that virtually all of the evidence concerning both the intramodal and cross-modal orienting of tactile spatial attention reported to date has been collected under conditions where participants were seated in a dark room, and where they typically had absolutely nothing

else to do other than to respond to the periodically presented tactile targets while trying to ignore any mildly distracting cue stimuli (that were either presented in the same or different modality). While such “sensorially restricted” research has certainly helped cognitive scientists to demonstrate that the exogenous orienting of attention and IOR can both be elicited by, and affect the processing of, tactile stimuli, it is important to note that such situations are nevertheless far from representative of the chaotic multisensory scenes that tend to fill people’s everyday lives. What’s more, given that researchers have recently started to investigate the potential utility of presenting tactile cues in order to capture the attention of an interface operator (see Chapter 10), it is clearly important to ascertain whether or not such tactile cues (or warning signals) will still be capable of capturing a person’s attention under more stimulating (and ecologically valid) testing conditions.

Santangelo and Spence (2009) conducted a laboratory study that was designed to investigate whether the abrupt onset of tactile stimuli (presented unpredictably to their participants’ left or right hands) would still capture their spatial attention when their visual attention was directed elsewhere. The participants performed a version of the tactile exogenous spatial task reported by Spence and McGlone (2001). However, the main difference from Spence and McGlone’s earlier study was that a rapidly changing stream of visual characters (with a new item being presented every 112 ms) was presented on a screen placed directly in front of the participants in certain blocks of trials. The centrally presented rapid serial visual presentation (RSVP) stream consisted of a random stream of letters, interspersed occasionally by a digit.

In the baseline spatial cuing blocks (where no RSVP stream was presented), Santangelo and Spence (2009) replicated the spatial cuing effects reported in Spence and McGlone’s (2001) earlier study. However, this spatial cuing effect was completely eliminated by the presentation of the central RSVP stream (no matter whether the participants had to monitor the RSVP stream and respond to the target digits or not). These results therefore provide some of the first empirical evidence in support of the notion that the exogenous spatial orienting of attention toward abrupt-onset tactile stimuli is not actually as automatic as had traditionally been thought (see Spence, 2010b; Spence & Santangelo, 2009, for reviews). In particular, exogenous tactile attentional orienting does not appear to occur when a person’s cognitive resources are utilized by a concurrently presented stream of rapidly changing visual stimuli (though see also Ho et al., 2005, 2006a). Further evidence pointing to the same conclusion comes from another study by Chica, Sanabria, Lupiáñez, and Spence (2007) in which the magnitude of the spatial cuing effects elicited by the presentation of tactile cues presented to either hand were also shown to be modulated by whether the cue predicted that a subsequently presented target stimulus would be presented on the same versus opposite side (varied on a block-by-block basis).

The simultaneous presentation of a rapid stream of auditory or visual stimuli will also eliminate both intramodal auditory, and perhaps more surprisingly, intramodal visual spatial cuing effects as well (Santangelo, Belardinelli, & Spence, 2007a). However, while intramodal tactile, intramodal auditory, and intramodal visual spatial cuing effects are all eliminated by the central presentation of a RSVP stream (which participants have to monitor), multisensory cuing effects (such as those elicited by the presentation of an audiotactile or audiovisual cue) appear to be entirely resistant to such load manipulations (see Ho, Santangelo, & Spence, 2009; Santangelo & Spence, 2009). Such results therefore suggest that multisensory events (i.e., cues) may have a “genuinely automatic” ability to capture a person’s spatial attention no matter what else they happen to be doing at the same time (Spence, 2010a, b). By contrast, unimodal cues (be they tactile, auditory, or visual) only appear to be effective (in terms of triggering an exogenous shift of a person’s spatial attention to the cued location) under conditions of relatively subdued sensory stimulation or low task demand (see also Santangelo, Fagioli, & Macaluso, 2010).

It is, however, not just manipulations of perceptual load that modulate spatial cuing effects. Loading a person's working memory can also exert a small, but nevertheless still significant effect on selective attention (Dalton, Lavie, & Spence, 2009; Lavie & de Fockert, 2005; Zimmer & Macaluso, 2007). In particular, Polly Dalton and her colleagues have demonstrated that loading a person's working memory (by requiring them to hold a random string of visually presented digits in memory for subsequent recall) interferes with their ability to perform a tactile selective attention task, based on the distractor congruency task first reported by Soto-Faraco et al. (2004; see also Legrain, Crombez, & Mouraux, 2011, for similar results regarding people's attention to nociceptive stimuli). The research reported in the preceding sections of this chapter has hopefully conveyed just how far researchers have come in the last decade or so in terms of developing an understanding of the behavioral constraints (and to a certain extent the neural underpinnings) underlying our ability to attend to tactile stimuli. The empirical evidence now unequivocally demonstrates that people can voluntarily direct their spatial attention to a particular location (or to a part of the body) and that this speeds up the processing of tactile (and other) stimuli that happen to be presented subsequently from the attended location (when compared to the performance seen for targets presented at other "relatively less attended" locations). Similarly, the sudden presentation of a tactile stimulus has also been shown to lead to a relatively automatic (or stimulus-driven) shift of spatial attention under a variety of different conditions. Researchers have, however, also made clear that these exogenous attentional effects are not as reflexive as was traditionally thought (e.g., Chica et al., 2007; Santangelo & Spence, 2009; see also Dalton et al., 2009). In the coming years, it will be particularly important to study these interactions between the top-down and bottom-up control of spatial attention further, given that the focus of our attentional in daily life is typically modulated by the interplay of both internal and external factors.

6.8 The attentional limitations on tactile information processing across the body surface

Thus far, the research that has been highlighted in this chapter has dealt primarily with people's ability to process a single tactile stimulus presented to a specific point on their body surface. However, one area of growing research interest concerns the cognitive (attentional) limitations associated with the processing of more complex arrays of tactile stimuli presented over the body surface (including the hands and torso). In part, this research has been driven by the recent growth of interest in the potential use of touch to present more complex information to drivers (or other interface operators) whose visual attention may be overloaded (e.g., Asif, Boll, & Heuten, 2012; Jones, Lockyer, & Piatetski, 2006; Van Erp & Van Veen, 2004; see Chapter 10), or else for those individuals who have lost the use of one or more of their other senses (e.g., Bach-y-Rita, 1972, 2004; see also Poirier, De Volder, & Scheiber, 2007). In fact, there's a long history of research looking at the lower-level constraints (i.e., those primarily due to the physiological characteristics of the tactile sensory system) on a person's ability to process multiple tactile stimuli when presented simultaneously (or in a rapid sequential manner) over the body surface (see Chapters 3 and 4). However, it is equally important to note that there has been far less research that has specifically attempted to elucidate the higher-level (i.e., cognitive) and attentional limitations on the processing of more complex patterns of tactile stimulation presented to the skin.

In fact, research over the last decade or so on the phenomenon of the tactile attentional blink (e.g., Dell'Acqua, Jolicouer, Sessa, & Turatto, 2006; Hillstrom, Shapiro, & Spence, 2002; Soto-Faraco, Spence, Fairbank, Kingstone, Hillstrom, & Shapiro, 2002; see also Lipp, Neumann,

Pretorius, & McHugh, 2003) has revealed that people can find it difficult to process sequentially presented tactile stimuli (or patterns of stimulation). What's more, just as was highlighted in Chapters 3 and 4, several studies have demonstrated that people's ability to process multiple tactile stimuli presented over the body surface (see Figure 6.2), or even across the fingertips, is extremely limited (see Chapter 4). That is, people are simply unable to count more than two or three tactile stimuli accurately (see Gallace et al., 2006a, 2007b, 2008a; Riggs et al., 2006). Interestingly, even when the tactile stimuli are presented repeatedly (i.e., once a second for a period of 10 seconds), in order to allow participants sufficient time in which to direct their attention sequentially across their body in order to determine whether each tactor was on or not (cf. Lakatos & Shepard, 1997b), performance improved somewhat but was still far from perfect (Gallace et al., 2006b).

Given such apparently severe constraints on the enumeration of the stimuli that happen to be presented in a tactile display, it is perhaps not so surprising that the phenomenon of change blindness (i.e., the surprising inability of people to perceive changes between successively presented visual scenes when separated by temporal gaps or different form of disruptions; see Simons & Rensink, 2005, for a review) has also been shown to affect the processing (and hence the perception) of the stimuli in tactile displays (see Chapter 4).

Tactile change blindness can be demonstrated by presenting very simple displays composed of as few as three or four stimuli presented on different body positions. By contrast, visual change blindness occurs with more complex arrays of stimuli or visual scenes (e.g., Galpin, Underwood, & Crundall, 2009; Grimes, 1996; Simons & Levin, 1997). By itself, that observation would seem to suggest that people's ability to monitor tactile information is affected by more severe limitations than the same ability within the visual modality.

The results described in this section, and those summarized in Chapter 4, certainly highlight the severe limitations that constrain people's ability to process multiple sensory stimuli presented across the body surface. It is important to note that, just as for the case of the tactile numerosity judgments described earlier, similar change blindness effects also influence the processing of tactile stimuli presented on the fingertips (see Auvray, Gallace, Tan, & Spence, 2008). Consequently, these limitations in tactile information processing cannot simply be attributed to the difficulties that people might have in terms of attending to tactile stimuli presented to their body surface (i.e., something that most people are relatively unfamiliar with). From a practical point of view (i.e., when thinking about the implementation of navigational displays, for example, in cars; see Van Erp & Van Veen, 2004; Spence, 2012a), it should be noted that tactile change blindness can be induced by the presentation of a visual mask (or visual mudsplash) in the interval between the presentation of the two tactile patterns (see Figure 6.2d; Auvray, Gallace, Tan, & Spence, 2008; Gallace, Tan, & Spence, 2006b). One final limitation with using tactile displays to present directional information (as when using the apparent motion of a tactile display across the body surface) to bear in mind here stems from the fact that the perceived direction of a tactile display across the fingertips, fingers, or hands, can also be altered by any visual stimuli that happen to be moving at around the same time (see Bensmaia, Killebrew, & Craig, 2006; Craig, 2006; Lyons, Sanabria, Vatakis, & Spence, 2006).

Even if the results summarized in this section would appear to suggest that severe limitations affect people's ability to deploy their attention toward touch, one should also note that at least some of these limitations might be a byproduct of the means adopted by researchers to study this sensory modality. In fact, while within an experimental setting, visual information can be completely controlled by the experimenter (e.g., by performing the experiment in a dark room, while presenting the stimuli on a PC screen), in a tactile experiment, a considerable amount of information (somatosensory and proprioceptive) might still affect the participant's performance

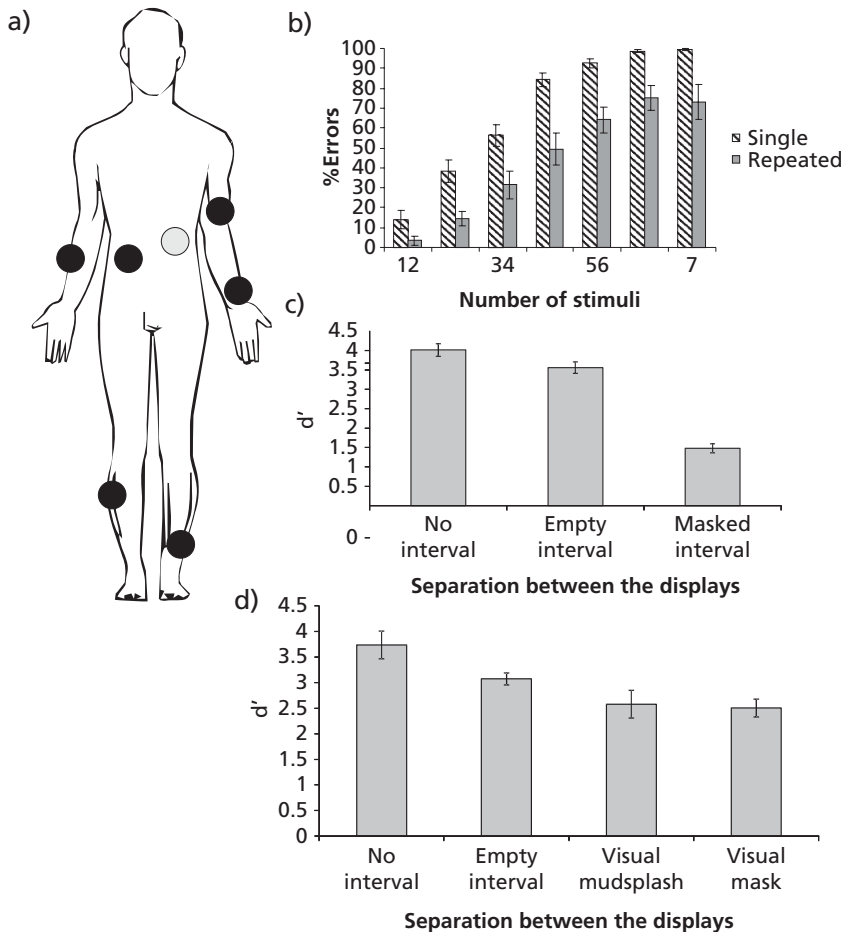


Fig. 6.2 Experimental set-up and results from Gallace et al.'s (2006a, b, 2007b) studies highlighting the severe attentional/cognitive limitations that people experience when trying to process complex displays of tactile stimuli presented across their body surface. (a) Positions on the body where the tactors and the visual distractors (LED lights) were placed in all three studies. (b) Results of Gallace et al.'s (2006b) study of tactile numerosity judgments obtained under conditions of either single or repeated stimulus presentation. (c) The results of Gallace et al.'s (2006a) unimodal study of tactile change detection. In the No interval condition, the two to-be-compared tactile patterns were presented sequentially, without any gap between them. In the empty interval condition, the two patterns were separated by a 110 ms empty interstimulus interval. In the Masked interval condition, the two patterns were separated by an interval consisting of a 50 ms empty interval, followed by a 10 ms vibrotactile mask consisting of all seven tactors being activated simultaneously, and then finally by a second 50 ms empty interval. The mean d' values represent the perceptual sensitivity of participants' change detection performance (i.e., the higher the value, the more sensitive the participants were to the presence of change). The error bars represent the standard errors of the means. (d) Results of Gallace et al.'s (2007b) visuotactile change detection study. Note that in the Visual mudsplash condition, a visual distractor consisting of the brief illumination of one of the LEDs was presented at the same time as the onset of the second vibrotactile pattern (see also Chapter 4).

(e.g., think only of the participant's contact with the chair or desk, and any signals concerning the current position of his/her joints). That is, before coming to any conclusion about potential differences between tactile and visual or auditory attention researchers in this field should also consider these factors.

6.9 Conclusions

As we noted at the start of this chapter, the majority of the attention research published over the last 50 years or so has focused on the selection taking place within either just the auditory or just the visual modalities. However, the last decade has seen a dramatic increase in the number of studies directed at studying tactile (and multisensory, or crossmodal) attention. As a result, we now know far more than ever before about the behavioral constraints on people's ability to process tactile stimuli presented on the hands, as well as to the rest of the body surface. Currently, the evidence overwhelmingly supports the view that people can direct their attention toward a particular part of their body (or region of space where that part of the body happens to be) in order to facilitate the processing of any tactile stimuli that may subsequently be presented there. Directing attention to interoceptive signals, arising from within the body, can also enhance the processing of stimuli presented on the body surface (e.g., Lloyd et al., 2008; Mirams et al., 2012). Similarly, spatial attention can also be drawn to the location of an abrupt onset stimulus (be it tactile, auditory, or visual) presented on, or near to, the body (see Spence, 2010b; Spence et al., 2004, for reviews). The extant research now highlights the existence of extensive crossmodal links in spatial attention, links that are typically updated following changes in a person's posture (such as the crossing of the hands, or the deviation of the head with respect to the body; see Spence & Driver, 2004, for a review; though see also Driver & Spence, 1998; Röder et al., 2002).

Cognitive neuroscientists have now started to investigate the nature of the interaction between the top-down and bottom-up control of tactile spatial attention (see Chica et al., 2007; Dalton et al., 2009; Santangelo & Spence, 2009), and this appears to represent a promising area for future research. Furthermore, having now identified a number of the behavioral limitations on tactile attention and information processing, further investigation should be addressed to the neural mechanisms underpinning these behavioral effects, just as extensively done for the study of visual attention (see Burton & Sinclair, 2000; Burton et al., 2008; Forster & Eimer, 2005; Gherri & Forster, 2012a, b; Kennett et al., 2001; Kida et al., 2007; Macaluso, Frith, & Driver, 2000; Vibell et al., 2007). The link between tactile attention and our awareness of somatosensory stimuli, comprising those stimuli that are perceived as painful (in normal and clinical populations), is another important area where research will likely concentrate in the years to come (e.g., Gallace et al., 2011; Moseley et al., 2008a; see also Van Hulle, Van Damme, Crombez, Spence, & Gallace, 2013). However, in our opinion, perhaps the most exciting area for future research relates to the design of tactile interfaces for everything from the presentation of navigational and gravitational information (see Chapter 9), to the capture of attention while driving (Ferris et al., 2006; Ho et al., 2005, 2006a, 2007a, b; see Chapter 10). Given recent laboratory-based research highlighting some fairly severe limitations in people's ability to process/perceive multiple stimuli presented at the same time across the fingertips or the rest of the body (Gallace et al., 2005, 2006a, 2008a; Riggs et al., 2006; see also Rabinowitz, Houtsma, Durlach, & Delhorne, 1987; Chapter 4), new insights will be needed in order to figure out a way in which to present more complex information to a person without exceeding their limited ability to process it. Having discussed how our brain can process, remember, and select emotionally neutral tactile information, Chapter 7 will deal with the more social and emotional aspects of touch.

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Chapter 7

A caress on your skin: The social aspects of touch

We believe that contact comfort has long served the animal kingdom as a motivating agent for affectional responses.
(*Harlow, 1958, p. 676*)

7.1 Introduction

As mentioned already (see Chapter 1), touch is the first of our senses to develop, and it provides us with our most fundamental means of contact with the external world. Touch provides us with an often-overlooked channel of communication (e.g., Burgoon, Buller, & Woodall, 1996; Finnegan, 2005; Frank, 1957; Geldard, 1960, 1961; Hertenstein, 2002; McDaniel & Andersen, 1998), and interpersonal touch plays an important role in governing our emotional well-being (e.g., Field, 2001; Spence, 2002b). Whether a strong handshake, an encouraging pat on the back, a sensual caress, a nudge for attention, a tender kiss, or even a gentle brush against the shoulder, physical contact can convey an immediacy and vitality that, at times, can be more powerful than language (Jones & Yarbrough, 1985). Our personal experiences would appear to suggest that even the briefest of touches from another person can elicit strong emotional responses; from the comforting experience of being touched by one's spouse, to the anxiety experienced when we are unexpectedly nudged by a stranger (see Gazzola, Spezio, Etzel, Castelli, Adolphs, & Keysers, 2012; Guest, Essick, Dessirier, Blot, Lopetcharat, & McGlone, 2009).

We use touch to share our feelings with others, and to enhance the meaning of other forms of verbal and non-verbal communication. For example, our eye contact with other people means very different things depending on whether or not we also happen to touch them at the same time. As Field (2001, p. 57) has pointed out, "Touch is ten times stronger than verbal or emotional contact, and it affects damned near everything we do. No other sense can arouse you like touch . . . We forget that touch is not only basic to our species, but the key to it." In fact, interpersonal touch plays a very important role in our early social interactions and our first lessons in loving often tend to come through the cuddling we receive as infants (e.g., Harlow, 1958). Early tactile sensations can shape our memories and thus drive our future behavior as Sheldon and Arens pointed out back in the 1930s: "It may need a trained psychologist to discover that the choice of a man's wife was determined by the memory of the soft silkiness of his mother's hair" (Sheldon & Arens, 1932, p. 100; see also Chapter 6, for a review of tactile memory). Of course, touch assumes an even stronger role in romantic relationships in adulthood: "I could die for the touch of a woman like thee" was how the novelist D. H. Lawrence (1928, p. 135) put it in one of his novels.

On the other hand, a shortage of touch often carries with it negative connotations, as captured by terms such as "out of touch with reality" and "tactless," while a deeply felt experience is often

described as “touching” (Montagu, 1971, p. 5). As we will see later in this chapter, interpersonal touch can also provide a powerful means of gaining the compliance of another, or when trying to persuade someone of something (such as in the “Midas touch” effect; see Crusco & Wetzel, 1984).

The sense of touch provides a very powerful means of eliciting and modulating human emotion. In fact, our skin contains receptors that can trigger emotional (sometimes referred to as affective or hedonic) responses (e.g., Valentini, Kischka, & Halligan, 2007; Weiskrantz & Zhang, 1989), either because there are portions of the skin that are erogenous and directly deliver positive affect, or because there are nerve endings that respond to pain and deliver negative affect (see Auvray, Myin, & Spence, 2010; Winklermann, 1959; see Chapter 2). Certain parts of the brain, such as, for example, the orbitofrontal cortex, respond specifically to “pleasant touch,” such as the feel of velvet on the skin (Francis, Rolls, Bowtell, McGlone, O’Doherty, Browning, Clare, & Smith, 1999).

Interpersonal touch provides the most emotional of our tactile experiences. That said, in many situations nowadays, interpersonal touch is actively discouraged, due to the threat of potential litigation and/or changing public attitudes (e.g., Field, 2001; Ingham, 1989; Piper & Smith, 2003; Routasalo & Isola, 1996; see also McKinney & Kempson, 2012, for the decrease in the amount of tactile contact by social workers in recent years). Dr. Tiffany Field, Director of the Touch Research Institute, in Miami, Florida (who has written well over 100 research articles documenting the beneficial effects of interpersonal touch on health and well-being), has asserted that many people in society today may actually be suffering from a shortage of tactile stimulation, a phenomenon which she evocatively refers to as “touch hunger.”

Despite its importance for our emotional well-being, the study of the interpersonal and emotional aspects touch have been somewhat neglected by cognitive scientists over the years.¹ Far more research appears to have been devoted to investigating the more emotional aspects of our other senses, such as vision and audition (and to a lesser extent olfaction and taste), than of our sense of touch (e.g., Ekman, 1993; Ekman, Friesen, & Ellsworth, 1972; Fecteau, Belin, Joanne, & Armony, 2007; Johnstone, van Reekum, Oakes, & Davidson, 2006; Nass & Brave, 2005; O’Doherty, Rolls, Francis, Bowtell, & McGlone, 2001; Veldhuizen, van Rooden, & Kroeze, 2006).

Studying the cognitive and neural correlates of interpersonal touch together with the more cognitive aspects of tactile perception (see the previous chapters in this book) seems then to constitute an important issue at present. Indeed, the development and diffusion of Internet-based technologies has created the opportunity to easily (and at little, or no, cost to the customer) interact with people who may be many miles away. However, these advances have occurred at the expense of the more physical and, in particular, tactile aspects of our interpersonal communication (see also Finnegan, 2005). Researchers in a number of different fields of study are therefore now actively thinking about how to try and bring back touch into Internet and VR settings (e.g., see Smith & MacLean, 2007; see Chapter 9, for a discussion of the likely impact of these technologies). It is our belief that we may actually be on the verge of a new era of multisensory virtual communications. However, before any real progress can be made in terms of enhancing the realism in the area of virtual or mediated touch, more research will be needed in order to better understand the more cognitive aspects of interpersonal tactile communication. Similarly, those topics, such

¹ Note that the present chapter does not deal with the extant research that addressed the effect of massage on people’s emotional state and well-being. This topic has been extensively reviewed elsewhere (e.g., see Field, 1998; Field, Hernandez-Reif, Diego, Schanberg, & Kuhn, 2005; Field, Ironson, Pickens, Nawrocki, Fox, Scafidi, Burman, & Schanberg, 1996).

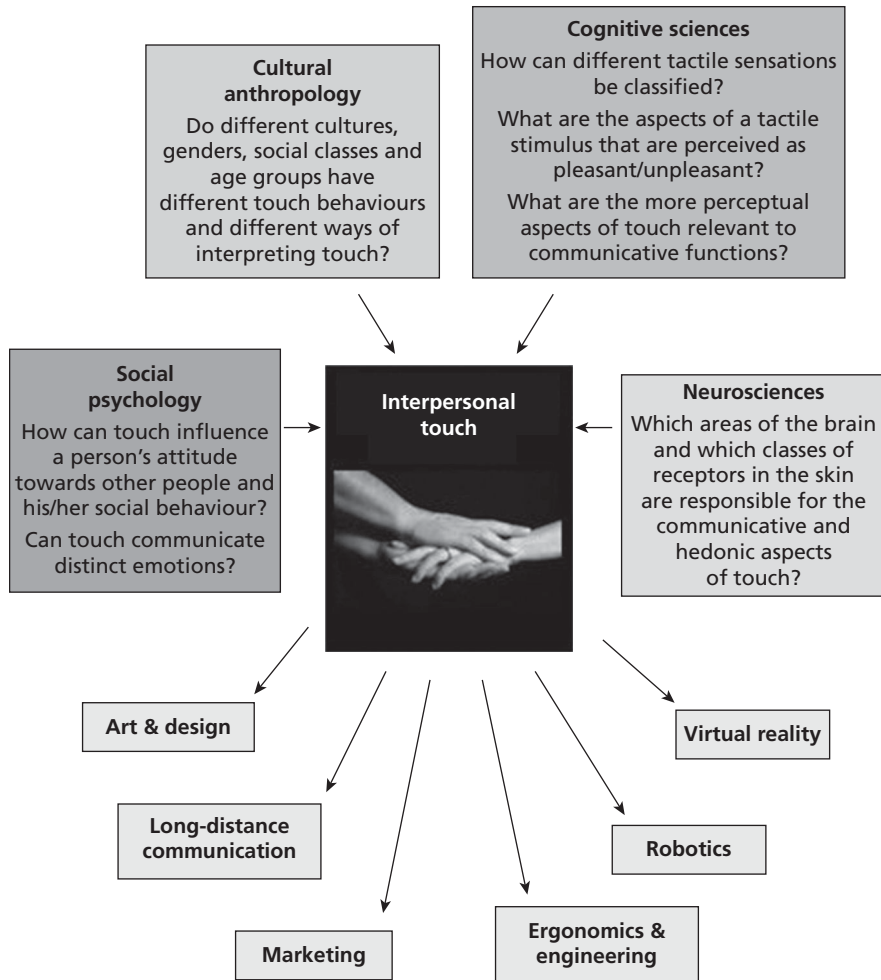


Fig. 7.1 Schematic representation of the key disciplines that are relevant to research on the topic of interpersonal touch (together with some of the questions which arise from them) and of the domains that can benefit from the study of this topic.

as the emotional and hedonic aspects of tactile sensations that are closely related with that of interpersonal touch also need to be addressed at the same time (see Figure 7.1, for the disciplines relevant to its study.). This would certainly help to develop a fuller understanding of this field in the years to come.

7.2 The effects of age, gender, and cultural differences on interpersonal touch

Before reviewing the extant literature on the role of tactile stimulation in interpersonal communication, it is worth noting the important function that background and culture can play in modulating our interpretation of, and hence response to, interpersonal touch (e.g., Jourard,

1966; Maines, 1977; Shuter, 1977; see also Andersen, 2012). Most people's personal experience provides numerous examples of individuals from certain cultures touching each other more often than those belonging to other cultures. For example, in Italy, a big hug and kiss on each cheek is considered a common and acceptable form of greeting. By contrast, in Japan the proper greeting consists of a respectful bow and the absence of any tactile contact whatsoever (see also Finnegan, 2005; McDaniel & Andersen, 1998). Following on from these everyday observations, the empirical research that has been conducted in this area has confirmed that people from the United Kingdom, certain parts of Northern Europe, and Asia touch each other far less frequently than those living in France, Italy, or South America (e.g., Jourard, 1966; see also Henley, 1973).

For example, the couples observed in coffee-shops in San Juan, Puerto Rico by Jourard (1966) touched each other an average of 180 times per hour, while those in London cafes didn't touch each other at all! The setting in which people interact can, of course, also affect interpersonal touch (e.g., Burgoon, Buller, & Woodall, 1989). For instance, at airport departures and arrivals lounges, approximately 60% of individuals engage in at least some form of interpersonal touch, and quite often in multiple acts of touching between couples (i.e., a comparatively higher rate than that documented in coffee shops and other public places; see Heslin & Boss, cited in Smith, Willis, & Gier, 1980; see also Greenbaum & Rosenfeld, 1980, for a study highlighting the gender differences that exist in the greeting of airline travelers). Similarly, in an observational study of preschool children at play, Williams and Willis (1978) reported higher rates of interpersonal touch when the children were playing outside as compared to when they were playing inside. Field observations have also confirmed that the rate of interpersonal touch following sporting success (in this study, ten-pin bowlers were observed during league play; Smith et al., 1980) is much higher than that reported in other public settings (and, what is more, was no different for male as compared to female teams).

Belonging to a certain gender and age group can though sometimes have a profound effect on a person's touching behavior. For example, during the preschool years and up to high school, same-gender pairs tend to touch more frequently than cross-gender pairs (see Williams & Willis, 1978; Willis & Hoffman, 1975; Willis, Reeves, & Buchanan, 1976). This effect is greater amongst females than amongst males. Interestingly, this relationship appears to change as a function of maturation. Indeed, college students (Willis, Rinck, & Dean, 1978) and adults in public shopping centers (Daniels, 1978, cited in Smith, Willis, & Gier, 1980) have rates of cross-gender touching that exceed those observed in same-gender touching. Furthermore, within cross-gender pairs, males are more likely to initiate the touching of the female than vice versa (e.g., Henley, 1973).

Tactile touching behaviors (i.e., social touch) certainly bear comparison to other forms of social interactions, such as eye contact, that occurs between people. In particular, it has been shown that girls and women are more likely than boys and men to engage in mutual eye contact with another person for longer periods of time, particularly if that person is female (e.g., Argyle & Ingham, 1972; Mulac, Studley, Wiemann, & Bradac, 1987). That is, the same-gender eye contact between females exceeds their cross-gender eye contact (just as has been reported for the case of tactile contact in childhood). Note, however, that this pattern of behavior may be "context-specific" and, in cross-sex interactions, boys and girls may exhibit different patterns of mutual gaze than that seen in same-sex interactions (Argyle & Ingham, 1972; Mulac et al., 1987). The similarities and differences between visual and tactile forms of social interactions and the modulating role of context in such aspects of behavior, certainly deserve further investigation (see St. John, 2006, for the use of touch in a political context).

To summarize, the observations reported in this section clearly suggest that age and gender differences, together with cultural factors, need to be taken into account when investigating the role of touch as a means of interpersonal communication (see Gumtau, 2005a, for a discussion of the role of cultural context in tactile communication).

7.3 Research on the consequences of interpersonal touch

The power of interpersonal touch in different kinds of interpersonal interactions has been demonstrated in many different studies over the last three decades or so (see Thayer, 1982, 1986, 1989, for reviews). For example, in one of the classic studies to have been published in this area, Fisher, Rytting, and Heslin (1976) asked male and female clerks to return library cards to students and while doing so instructed them to place their hands directly over the students' palms, making physical contact; other students, by contrast, were not touched. The researchers reported that the students' evaluation of the library was more favorable if the library clerk "accidentally" touched them. Interestingly, this effect occurred despite the fact that none of the students could remember having been touched by the librarian (see also Erceau & Guéguen, 2007, for a similar result showing the people rate the salesmen and women at car showrooms more favorably if they had been touched by them).

It is important to note that the results of the studies reported thus far in this section were all obtained using post-observation questionnaires in ecologically valid (as compared to controlled laboratory) conditions. As such, it is difficult to determine whether the participants who had been interviewed really had been unaware of the touch at the time that it occurred (e.g., when the card was returned by the clerk in Fisher et al.'s, 1976, study) or whether instead they had been aware of the touch but then simply forgot that they had been touched a short time thereafter (see Wolfe, 1999, for a similar distinction between blindness and amnesia for previously presented visual stimuli).

Subsequent research by Hornik (1991, 1992; Hornik & Ellis, 1988) has demonstrated that interpersonal touch can also be very important in a consumer (i.e., store) setting. In particular, Hornik reported that customers tend to be far more compliant in their behavior (that is, in terms of responding positively to a tasting and purchasing request) in a supermarket when they are touched by an experimenter posing as a store assistant than when no one touches them (Hornik, 1992). Working along similar lines, Kleinke (1977) observed that people are significantly more likely to return a dime left in a phone booth if the preceding "telephone caller" touched them than if he/she had not.

Guéguen (2004) reported an experiment in which students were encouraged to demonstrate the solution to a given statistical exercise that had been presented on the blackboard in a classroom setting. A number of the students were briefly touched on their forearm by the teacher during the exercise while the others were not. Next, the teacher asked the students to demonstrate the solution to the exercise on the blackboard. Touching was found to increase the rate of volunteering by the students (see also Field, Ironson, Pickens, Nawrocki, Fox, Scafidi, Burman, & Schanberg, 1996). Hornik and Ellis (1988) have also demonstrated that individuals who have been touched are more likely to agree to participate in a mall interview.

Elsewhere, Crusco and Wetzel (1984) examined the effects of two types of touch in a restaurant setting. The waitresses in this study were instructed to briefly touch customers either on the hand, on the shoulder, or not to touch them at all as they were returning their change after they had received the bill. Crusco and Wetzel used the size of the tip given by the customer to the waitress as their independent variable. Surprisingly, the researchers found that the tipping rate

of both male and female customers was significantly higher in both of the touching conditions than in the baseline no-touch condition (a phenomenon that has been labeled the “Midas touch” effect; e.g., Crusco & Wetzel, 1984; Erceau & Guéguen, 2007; Stephen & Zweigenhaft, 1986; see also Kaufman & Mahoney, 1999). Meanwhile, other researchers have reported that bus drivers are more likely to give a passenger a free ride if they touch him while making the request than if they do not (Guéguen & Fischer-Lokou, 2003). Along similar lines, Joule and Guéguen (2007) demonstrated that people are more likely to give someone a free cigarette if the request comes from a person who touched them at the same time.

More recent studies on the Midas touch effect have revealed that the gender of the person who delivers the touch might also be relevant for the effect to occur (at least in particular contexts). In particular, Levav and Argo (2010) reported that both men and women who were lightly touched by a woman on the back were more likely to take larger financial risks in an investment game than those who had not been touched, or else who had been touched by a male confederate. That is, the take-home message here might be: Be careful when making important financial decisions if a woman is standing close by! Finally, it is important to mention here that there are also situations where touch might not exert such a positive effect on people. In particular, a recent study by Martin (2012), reported that those who were touched by another customer when examining the products in a store valuated brands more negatively, spent less time in the store, and reported that they were willing to pay about 40% less for a particular item than untouched shoppers (note that this effect was even stronger when it was a male doing the touching). The results of this study might be taken to suggest that, within certain situations (at least when people are aware of having been touched), people’s behavior is not affected by touch *per se*, but by the meaning that is given to the tactile interaction.

At present, it is somewhat unclear why interpersonal touch should have such a powerful effect on people. Rose (1990) has argued that these effects may be due to cognitive interpretational factors. That is, the recipient tends to assume that the “toucher” is in genuine need and that the toucher likes and trusts him. The perception of either great need or a positive feeling in turn tends to increase compliance rates (see also Patterson, Powell, & Lenihan, 1986). However, although this interpretation might provide an effective means of interpreting the results of those studies in which the “subject” was aware of the other person’s touch, it appears more difficult to extend it to those conditions in which the “touched” person reported being unaware of the other person’s touch (at least if one assumes that interpretational factors act upon a more explicit level of tactile information processing).

A somewhat different suggestion comes from Reite (1990). He claimed that the normal association between touch and stress reduction in early childhood may result in a positive response to being touched in later life (note that this may suggest that the effects of interpersonal touch are related to automatic and perhaps implicit mechanisms). Alternatively, however, the positive effects of interpersonal touch (e.g., in eliciting compliance with specific requests) may also relate to the fact that there are receptors in the human skin that appear to code for pleasant touch (e.g., Vallbo & Johansson, 1984; see McGlone et al., 2007, for a review). In this case, the information regarding the situation or the interpersonal context where touch is generated might be neurally linked with the pleasant sensations elicited by the touch itself. Reite’s interpretation has the advantage of being able to account for the results of those studies in which the participants reported having been unaware of being touched. Indeed, emotional responses can be elicited (likely mediated by subcortical neural pathways; e.g., Morris, Ohman, & Dolan, 1999) without the explicit coding of the stimuli that gave rise to them (e.g., Kunst-Wilson & Zajonc, 1980).

The interpretation that relates the positive effects of touch on humans to the stimulation of receptors that code for pleasant touch still needs further corroboration. Indeed, the conductive neural fibers (CT afferents) that mediate pleasant touch appear to respond particularly vigorously to the slow stroking of the skin, but relatively poorly to rapid deformations of the skin surface (e.g., Bessou, Burgess, Perl, & Taylor, 1971; Iggo, 1960; see also Olausson et al., 2008; see Chapter 2). Therefore, the activation of such a neural mechanism would seem better able to explain the results of those situations in which the “participants” were stroked but not those where a single abrupt touch was delivered. Moreover, one must also consider the possibility that people’s beliefs about who is actually touching them (when the eliciting stimulus remains constant) might also play an important role in mediating the effects reviewed in this section (see also section 7.4. for evidence suggesting that the characteristics of the persons who deliver the touch affects the neural activity generated by the tactile stimulus).

As far as the link between the neural correlates of tactile sensations and interpersonal social interactions is concerned, it is interesting to highlight the relationship that has been reported between touch and certain disorders involving pathologically abnormal social behaviors, such as autism (e.g., Cascio, McGlone, Folger, Tannan, Baranek, Pelphrey, & Essick, 2008; McGlone et al., 2007; see also Spitz & Wolf, 1946). Specifically, Zwaigenbaum, Thurm, Stone, Baranek, Bryson, Iverson, et al. (2007) reported that 70% of those individuals affected by autism exhibit some form of sensory-perceptual anomaly. Such an observation is consistent with the recent report that children with autism exhibit a reduced neuronal response in S1 to tactile stimuli (taps) delivered to their fingers (Marco, Khatibi, Hill, Siegel, Arroyo, Dowling, Neuhaus, Sherr, Hinkley, & Nagarajan, 2012). Furthermore, many infants suffering from autism are averse to social touch (see Baranek, 1999). Moreover, it has also been claimed that a pathologically acute tactile sensitivity, or the inability to modulate tactile input, might interfere with social behaviors that involve interpersonal touch (see Grandin, 1992). The results of these various studies might therefore be taken to strengthen the claim that a change/abnormality in tactile sensitivity can have a major impact on a person’s social behaviors (see McGlone et al., 2007).

Finally, the effects of tactile contact have also been reported in the context of a variety of healthcare-related behaviors, and under conditions where specific physiological variables were measured (Barnett, 1972; Harrison, 1986; see also Routasalo & Isola, 1996, on the debate regarding the “right to touch and to be touched” in healthcare). For example, it has been reported that the simple act of touching a patient by a nurse on the day before a surgical operation can result in a decrease in the patient’s stress levels (both, as evaluated objectively by physiological measures such as heart rate and blood pressure, and when evaluated subjectively by the patients themselves; see Whitcher & Fisher, 1979; see also Wong, Ghiasuddin, Kimata, Patelesio, & Siu, 2013). Touching the patient can even increase their compliance with the preoperative recommendations given to them. However, it should be pointed out here that in this study, the positive effects of touching were only observed on female patients, whereas the reverse effect was found in male patients. Whitcher and Fisher argued that the differential effect on males and females could have been due to interpretational factors (that is, they suggested that the males may have equated the touch with being treated as an inferior, or dependent, individual, something which they have been socialized to reject), a claim that led Friedman (1980) to subsequently accuse these authors of being sexist.

Along similar lines, Eaton, Mitchell-Bonair, and Friedmann (1986) reported that when the service staff who were caring for elderly people combined their verbal encouragement to eat with tactile contact, they consumed more calories and protein. Perhaps somewhat surprisingly, these positive effects on eating behavior lasted for up to 5 days after the tactile contact. These

results would therefore appear to constitute yet another example of the effectiveness of interpersonal touch on people's compliance (one that in this case also resulted in beneficial physiological changes for the individuals concerned; see also Field, 2001).

In the latter studies (Eaton et al., 1986; Whitcher & Fisher, 1979), it is difficult to separate out the influence on people's behavior of tactile stimulation *per se* from the interaction between tactile stimulation and any visual and/or auditory components of the interpersonal contact (for example, the tone of voice and/or the facial expression of the nurse). It would therefore be useful in future research to investigate the role of both congruent and incongruent stimulation presented from different sensory modalities in modulating the effect of interpersonal touch. That is, it seems at least possible that social touch might only prove to be effective when combined with (possibly disambiguating) congruent visual and/or auditory information. However, one cannot *a priori* exclude the possibility that tactile information may be capable of overpowering the communicative value of other sources of sensory stimulation, potentially leading to similar effects even when presented within incongruent multisensory settings (see also Finnegan, 2005).

As far as the role of different signals on the effects reported in this section is concerned, it should be noted that most of the studies that have investigated interpersonal touch are not immune from possible confounding influences. For example, the variability in the interpersonal distance between various experimental conditions and the fact that the confederate cannot be kept totally blind with respect to the experimental manipulations (and thus he/she might perhaps add further uncontrolled and involuntary social signals, such as a smile, to the experimental manipulation) might affect the compliance of participants in many of these experiments (see Lewis, Derlega, Shankar, Cochard, & Finkel, 1997, for a discussion of this point). As a consequence, the role of touch might have been over- or even under-estimated in previous studies. Certainly, the use of virtual, computer-mediated interactions (resulting in standardized experimental conditions), might offer an important contribution to the reduction of any bias that might have affected previous studies in this field (e.g., Haans et al., 2008; see Chapter 9).

As we have seen thus far, social touch can have a number of positive effects on people's behavior, but one might question whether this is true in all interpersonal contexts. As any traveler who starts to feel somewhat claustrophobic in an overcrowded train or underground carriage would be only too willing to testify, interpersonal touch certainly does not always carry a positive emotional valence. Unfortunately, only a few studies have thus far been addressed at investigating any negative effects of interpersonal touch (see Major, 1981; Walker, 1971).

A number of researchers have investigated those aspects of tactile behavior/sensations that are perceived to be "sexually harassing," and which are therefore described by people as having a negative affective valence (e.g., Gutek, Morasch, & Cohen, 1983; Johnson & Johnson, 1993; Lee & Guerrero, 2001). For example, people consider interpersonal touch to be much more harassing than normal verbal behaviors (Gutek et al., 1983; though see Dougherty et al., 1996). Unsurprisingly, the perception of touch as having a negative valence depends on the specific part of the body that has been touched, and on the specific characteristics of the person (such as his/her gender, age, and relationship with the touched person) who touches them.

Lee and Guerrero (2001), for example, reported that being touched on the face by an hypothetical co-worker was rated by participants as constituting the most inappropriate and harassing behavior (note also that the authors reported that touch on the face was rated as the signal that sends the strongest relational and emotional messages in intimate relationships as well). Touching the waist region was also considered as being relatively inappropriate and harassing, while tapping on the shoulder was reported to be the least harassing behavior. Results such as these therefore confirm that interpersonal touch may carry both positive and negative affective valence and that

the emotional valence that is carried depends on top-down cognitive factors such as gender, context, as well as on cultural factors (see Lee & Guerrero, 2001).

Here, it should be pointed out that Lee and Guerrero's (2001) results were obtained by presenting videotapes showing verbal and tactile interactions between actors and then asking the participants to complete a questionnaire (involving the presentation of Likert-type response scales) regarding the previously seen interactions. As a consequence, somewhat different, and perhaps even stronger, results might have been expected had the participants in the study been directly touched by another person as compared to the condition in which the participants were only asked to watch a videotape involving strangers touching one another (note, though, that McCabe, Rolls, Bilderbeck, & McGlone, 2008, have reported that the somatosensory cortex becomes significantly more active when participants observe someone else being touched; see also Banissy & Ward, 2007; Blakemore, Bristow, Bird, Frith, & Ward, 2005). Moreover, a post-stimulus questionnaire procedure might also enhance the effects of cultural factors (such as the moral judgments of the appropriateness of the tactile interactions) thus making a simple interpretation of Lee and Guerrero's results all the more difficult. Finally, note that Lee and Guerrero only investigated the effects of being touched on a limited number of body parts, such as the hand, waist, face, and shoulder.

In the future, it would certainly be interesting to investigate both positively and negatively valenced interpersonal (but also mechanical) tactile stimulation presented across more of the body surface using more controlled laboratory conditions (this is of particular interest because it would hopefully result in the development of a map of our responsiveness to interpersonal touch across the skin surface, i.e., somewhat akin to Weinstein's (1968) maps of the differing sensitivities of the various parts of the bodies of men and women to pressure, temperature, vibration, etc.). The creation of such a map might certainly be useful for the development of devices that would allow for long-distance interpersonal interactions (for example, helping to decide where to concentrate the tactile transducers on a VR body suit; see Chapter 9). Future studies should also help to differentiate the effects that are strictly related to tactile stimulation from those that depend upon any associated change in the interpersonal distance between two individuals. Note that if two people get too close, one of them may perceive a violation of his/her personal space even in the absence of any tactile stimulation (e.g., see Burgoon & Jones, 1976; Dosey & Meisels, 1969; Felipe & Sommer, 1966; Horowitz, Duff, & Stratton, 1964; Jourard & Friedman, 1970).

Another important aspect of interpersonal tactile communication relates to the question of whether or not touch can provide information regarding the emotional status of another individual. Indeed, previous research has shown this to be true of vision and audition (e.g., Ekman, 1993; Elfenbein & Ambady, 2002; Scherer, Johnstone, & Klasmeyer, 2003). Hertenstein, Keltner, App, Bulleit, and Jaskolka (2006) recently addressed this very topic in a study in which they investigated whether or not people could identify emotions from the experience of being touched by a stranger on their arm (without their necessarily being able to see the interpersonal touch itself). In order to do this, they randomly assigned a group of participants to the role of "encoder" or "decoder" of an emotional message. In each trial, the encoder and decoder sat at a table, separated by an opaque curtain that prevented the two people from seeing each other. Twelve words describing specific emotions (anger, disgust, fear, happiness, sadness, surprise, sympathy, embarrassment, love, envy, pride, and gratitude) were displayed serially to the encoder. The encoder was then instructed to think about how he or she wanted to communicate each emotion and then to make contact with the decoder's bare arm from the elbow to the end of the hand to signal each emotion, using any form of touch that he or she deemed appropriate. The decoder had to choose from amongst 13 response options which emotion word best described the message communicated by the encoder.

The results of this study revealed that interpersonal touch could be used to signal at least six different types of emotion, namely: anger, fear, disgust, love, gratitude, and sympathy. The participants in their study were able to decode the emotion in the range from 48% to 83% correct. These values are comparable to the success rates that have been observed in previous studies of the transmission and decoding of facial displays and vocal communication (e.g., Elfenbein & Ambady, 2002). These researchers were also able to identify the specific patterns of interpersonal touch used by their participants in order to communicate the distinct emotions. For example, while a combination of “hitting,” “squeezing,” and “trembling” (in this order of importance) was used to communicate “anger,” a combination of “pushing,” “lifting,” and “tapping” was used when “disgust” had to be communicated. Interestingly, a follow-up experiment by Piff, Purcell, Gruber, Hertenstein, and Keltner (2012) revealed that personality traits, such as a proneness to mania can affect the perception of emotion via touch. More specifically, those individuals who were prone to mania were found to have better tactile perception, especially related to emotionally positive stimuli. They also showed an over-attribution of positive and an under-attribution of negative emotions to all touches presented. These results then clearly suggest that touch can be successfully used to share the emotional aspects of communication between people, but once again they also highlight the fact that individual differences should be taken into account.

7.3.1 The healing power of touch?

Over the last two decades, there has been a steep increase of interest in the role of tactile contact within the medical field. In particular, osteopathy has become a progressively more important discipline in medical care worldwide (despite the fact that it was introduced more than a century ago by Andrew Taylor Still, an American physician, but that has only more recently become a recognized discipline in the majority of Western countries; Still, 1897; see also Hartmann, 2012; Howel, 1999).² Osteopathy (or osteopathic medicine) can be defined as a system of manual diagnosis and treatment for a range of musculoskeletal and non-musculoskeletal clinical conditions. It involves using the hands to diagnose, treat, and prevent illness or injury. In particular, without entering into a detailed discussion of this discipline, it can be said that in a typical osteopathic manipulative treatment, the clinician moves the patient’s muscles and joints using techniques including stretching, gentle pressure, and resistance. Importantly, one of the key aspects of this form of treatment has been claimed to be related to the relationship between touching and being touched (Elkiss & Jerome, 2012). That is, following on from these observations, social touch appears to play a major role in the healing process as determined by osteopathy.

A number of researchers have reported positive effects (especially in terms of recovery time after illness) of osteopathy on a number of diseases. For example, osteopathic manipulative treatment has been shown to be effective in improving kidney mobility and in reducing the perception of pain in the short term in those individuals suffering from non-specific lower back pain (e.g., Tozzi, Bongiorno, & Vitturini, 2012). The result of a recent meta-analysis performed on 12 studies involving 2887 participants where a combination of techniques including spinal manipulative therapy, massage, and thermotherapy were adopted revealed that these procedures slightly reduced pain and disability in the short term and pain in the medium term for those individuals

² This is how Dr. Still justified the need for an alternative form of medicine at the beginning of the last century: “known drugs have been a failure and the patient dies just as quickly with them, and often more quickly, than without them” (Still, 1902).

suffering from acute and subacute lower back pain (Walker, French, Grant, & Green, 2010; see also Tettambel, 2012; though see Cronholm & Nicklin, 2012, for a critical view on the effectiveness of spinal manipulation).³ It has also been shown that the addition of osteopathic manipulative treatment, or of light touch to conventional treatments, decreased the length of hospitalization, the duration of intravenous antibiotics, and the incidence of respiratory failure and death in patients affected by pneumonia relative to conventional care only (e.g., Goldstein, 2010; Noll, Degenhardt, Morley, Blais, Hortos, Hensel, Johnson, Pasta, & Stoll, 2010; see also Pizzolorusso, Turi, Barlafante, Cerritelli, Renzetti, Cozzolino, D'Orazio, Fusilli, Carinci, & D'Incecco, 2011, for a study on a cohort of 350 premature infants, showing that osteopathic manipulative treatment reduced gastrointestinal symptoms and the length of the stay in neonatal intensive care units). The effectiveness of osteopathic manipulation has also been reported in single cases studies. For example, Meyer and Gustowski (2012) recently demonstrated that cranial and cervical somatic dysfunction in a patient who had undergone tooth extraction was resolved through the use of osteopathic manipulative treatment. It is, however, important to note that the effectiveness of a given treatment must be validated on larger numbers of participants and by using randomized clinical trials, before any firm conclusions can be drawn (see Licciardone & Kearns, 2012; Parker, Heinking, & Kappler, 2012, for examples of clinical trials in this area).

It is worth bearing in mind at this point that the use of osteopathic procedures has often been vigorously criticized by the more conventional branches of medicine (e.g., Cronholm & Nicklin, 2012). In particular, one of the most important criticisms relates to the claim that osteopathy is not always based on solid empirical science, and that there is no robust evidence that osteopathy is effective for treating certain diseases (e.g., Ernst & Pittler, 1999; Hartman, 2006). Without entering into the debate as to whether or not such criticisms are fully justified, we believe that understanding the neuroscientific bases of the effects of interpersonal touch on health and well-being (e.g., which receptors and neural fibers are involved, what areas of the brain are activated, etc.) is likely to help the development of medical disciplines (or, more simply, medical procedures) based on haptic manipulation and/or tactile stimulation in the coming years (see, for example, the recent neurocognitive studies suggesting that the perception of pain can be modulated by changes in body posture and that these effects found their neurological basis in a decrease of activity in higher-order multisensory networks within the brain; e.g., Gallace et al., 2011; Torta, Diano, Costa, Gallace, Geminiani, & Cauda, submitted).

7.3.2 Touch between partners

Unsurprisingly, the importance of touch as a means of interpersonal communication has also been documented in romantic relationships (e.g., Gulledge, Gulledge, & Stahmann, 2003; Hollender, 1970; Montagu, 1979). Note that Montagu (1971) even went so far as to suggest that touch and love were indivisible! Gulledge and his colleagues used a questionnaire methodology in which they asked college students about their preferences and attitudes regarding different types of romantic physical affection (such as backrubs/massages, caressing/stroking, cuddling/holding, holding hands, hugging, kissing on the lips, and kissing on the face) and relationship satisfaction. They reported that tactile physical affection was highly correlated with overall relationship

³ Cronholm and Nicklin's (2012, p. 764) criticism of the effectiveness of spinal manipulation for the treatment of back pain can be summarized in the following claim: "Although a course of spinal manipulation, or physical therapy, may keep the patient happy (and occupied) while his or her pain spontaneously resolves, the improvement in pain and function is not based on large, quality studies."

and partner satisfaction. Note here, though, that gender differences might affect the perception of which sensory modality is actually considered more important for a satisfactory relationship/ and in choosing a potential partner (see Herz & Cahill, 1997; see also Nguyen, Heslin, & Nguyen, 1975). Clear confirmation of the important role of touch in interactions within the couple also comes from those experiments that have used more controlled experimental variables together with questionnaire measures.

The role of tactile affection on physiological variables such as blood pressure and heart rate has been investigated by Grewen, Anderson, Girdler, and Light (2003). These researchers studied the relationship between brief warm (i.e., emotional) social and physical contact among cohabitating couples and blood pressure reactivity to stress in a sample of healthy adults. In their study, the participants were randomly assigned to one of two different experimental groups; the “warm contact group” underwent a 10-minute period of handholding while viewing a romantic video. This was then followed by a 20-second hug with their partner. The no contact group rested quietly for 10 minutes and 20 seconds. After this section of the experiment, the participants in both groups had to perform a stressful public speaking task. The results revealed that those individuals who received pre-stress partner contact demonstrated significantly lower systolic and diastolic blood pressure, and heart rate increases than the no contact group. Given such results, it seems plausible to conclude that affectional physical behavior contributes to lowering an individual’s reactivity to stressful life events. Note, however, that it is also difficult in the case reported by Grewen et al. to completely separate the effects of tactile interaction from that related to the congruency of the tactile sensation with the global context in which it was generated (i.e., the sight of the partner, the videotape, etc.; cf. Moseley et al., 2008a).

A study by Ditzen et al. (2007) investigated whether specific kinds of physical interaction between a couple can reduce hypothalamic–pituitary–adrenal (HPA) and autonomic responses to psychosocial stress in women. The participants (women who had been married or cohabiting with their male partner for at least 12 months prior to the experiment) were randomly assigned to one of three study groups differing in the type of social interaction (lasting 10 minutes) with their partner that took place prior to stress: No interaction was allowed in one group; in another group, the women received verbal social support; and, in a third group, the women received a standardized form of physical contact, consisting of neck and shoulder massage. The participants were then exposed to a standardized psychosocial laboratory stressor (the Trier Social Stress Test; see Kirschbaum, Pirke, & Hellhammer, 1993). The results revealed that those women who received physical partner contact before stress exhibited significantly lower cortisol and heart rate responses to stress (although no significant differences in plasma oxytocin levels were reported) as compared to those women who received social support, or else who received no social interaction whatsoever. Of course, it is also possible in this case that interpersonal tactile contact might have interacted with other congruent aspects (visual, auditory, and even olfactory) of the social interaction with the partner.

A number of studies have investigated the role of touch between partners in mediating the release of oxytocin, a hormone that has been implicated in a variety of mammalian bonding behaviors (e.g., Bales & Carter, 2003; Bielsky & Young, 2004; Carter, 1998, 1999; Cho, De Vries, Williams, & Carter, 1999; Feldman, 2012; Insel, 2000; Insel, Preston, & Winslow, 1995; Liu, Curtis, & Wang, 2001; Porges, 1998; Young, 2002). Although the precise mechanisms by which pair bond formation occurs have not, as yet, been specifically delineated, it can be said with some degree of certainty that the release of oxytocin helps couples to form lasting relationship bonds (see Gullledge, Hill, Lister, & Sallion, 2007). Interestingly, oxytocin levels increase greatly during parturition, perhaps also helping to create an early bond between mothers and their

new-born infants (e.g., Kroeger, 1996). Sexual contact tends to induce the largest release of oxytocin (Williams, Catania, & Carter, 1992; Winslow, Hastings, Carter, Harbaugh, & Insel, 1993; see also Uvanas-Moberg, Arn, & Magnusson, 2005).⁴ However, non-sexual physical affection involving tactile stimulation such as back-rubbing and hugs also induces the release of oxytocin as well (see Shermer, 2004). What is more, women who report having been hugged more often by their partners in the past have higher levels of oxytocin and significantly lower blood pressure levels than those women who do not have much of a history of being hugged by their partners (Light et al., 2005). Following on from these observations, it is not surprising that certain forms of emotional support training among couples have started to make large use of tactile stimulation as a way of communicating affection and support. The positive effects of these procedures seem in fact related to an increase in the release of oxytocin following an enhancement in warm touch (e.g., Gordon, Zagoory-Sharon, Leckman, & Feldman, 2010; Holt-Lunstad, Birmingham, & Light, 2008).

As far as the role of touch on the more sexual aspects of interpersonal relationships is concerned, the few studies that have attempted to address this topic scientifically have primarily concentrated on the role of touch in sexual arousal (see Chapter 13). In particular, convergent evidence now suggests that tactile sensitivity may be associated with sexual arousal and that alterations in tactile sensitivity may impact upon sexual function. For example, Frohlich and Meston (2005a) reported that the tactile threshold measured at the fingertip was significantly correlated with the presence of female sexual arousal disorder (i.e., the higher the threshold the greater the severity of arousal dysfunction). Moreover, the women's tactile thresholds were linearly related to the severity of arousal dysfunction.

Taken as a whole, the results of the research that has been reviewed in this section would appear to suggest that tactile stimulation plays a very important role in interpersonal communication, in sexuality, and in creating bonds between people. This might occur, at least in part, at very early stages of information processing in the brain (i.e., mediated by hormone release).

7.4 The neuroscientific aspects of interpersonal touch

As should have become apparent from the review of the literature presented thus far in this chapter, we humans do not treat all of the different kinds of touch that we may experience in the same way (and as a consequence we respond to and perceive them in a number of different ways). In particular, our brains appear to discriminate between interpersonal touch, intrapersonal touch, and the passive touch of an object or surface on the skin (Bolanowski, Verrillo, & McGlone, 1999). What is more, it should also be noted that the majority of studies of interpersonal touch have investigated the consequences of interpersonal touch on non-glabrous (i.e., hairy) skin sites. By contrast, the majority of studies of tactile perception have involved people/participants touching (or being touched by), manipulating, and/or evaluating objects with their hands (i.e., using their glabrous or non-hairy skin). Now while introspection might lead one to assume that all of our skin surface is essentially the same (except for the fact that we are more sensitive on certain skin surfaces than others; e.g. see Weinstein, 1968; Winkelman, 1959), the latest research has revealed that certain classes of tactile receptors in the skin exist only in the non-glabrous skin but not in the glabrous skin (such as the hands, or the soles of the feet; see Chapter 2). These observations

⁴ See also Allen (2012) for the observation that use of an oxytocin nasal spray by those suffering from sexual problems can increase their libido.

can be taken to highlight the importance of testing different areas of the body when studying the more hedonic and interpersonal (as compared to perceptual and psychophysical) aspects of tactile information processing (cf. Weinstein, 1968; see also McGlone, Olausson, Boyle, Jones-Gotman, Dancer, Guest, & Essick 2012).

Recent cognitive neuroscience research findings have highlighted differential response seen in the brain to the more affective aspects of touch and affectively neutral tactile sensations (e.g., McGlone, Vallbo, Löken, & Wessberg, 2007; Olausson, Cole, Rylander, McGlone, Lamarre, Wallin, Krämer, Wessberg, Elam, Bushnell, & Vallbo, 2008; Rolls et al., 2003; see also Rolls, 2010). For example, Rolls et al. compared the patterns of brain activity produced by pleasant touch, painful touch (produced by a stylus), and neutral touch (consisting of the contact with the textured end of a wooden dowel), to the left hand using functional magnetic resonance imaging (fMRI). Rolls and his colleagues reported that regions of the orbitofrontal cortex (OFC) were activated more by pleasant touch and by painful stimulation than by neutral touch, and that different areas of the OFC were activated by the pleasant and painful touch. This activation was related to the affective aspects of the touch, in that S1 was less active following pleasant and painful stimuli than following the “neutral” stimulation.

Researchers studying the neural correlates of the more affective aspects of tactile processing have also suggested that the insular cortex might be an important component of a system responsible for our emotional, hormonal, and affiliative responses to tactile contact between individuals engaged in behaviors such as social grooming and nurturing (e.g., Olausson, Lamarre, Backlund, Morin, Walling, Starck, et al., 2002; Wessberg, Olausson, Fernstrom, & Vallbo, 2003). Here, it is relevant to point out that the insular cortex is now thought to contribute to the processing of convergent signals arising from different sensory channels, to produce an emotionally relevant response to a given sensory experience (e.g., see Nagai, Kishi, & Kato, 2007; see also Craig, 2002, 2009; Craig, Chen, Bandy, & Reiman, 2000). On the basis of such considerations, one might therefore hypothesize that part of the neural network responsible for the processing of certain emotional aspects of tactile experiences is actually shared with the network responsible for processing information from other sensory modalities.

One important point to be borne in mind here is that the majority of the studies that have addressed the neural correlates of emotional touch have used stimuli consisting of inanimate objects rather than interpersonal touch. Only a few recent studies have directly addressed this topic by means of neuroimaging techniques. For example, Kress, Minati, Ferraro, and Critchley (2012) investigated whether direct, skin-to-skin, interpersonal contact would be processed differently by the brain as compared to similar soft touch applied by means of inanimate objects. In particular, these researchers analyzed their participants’ brain activity when tactile stimuli, consisting of a gentle stroke or tapping on the forearms, were delivered using the experimenter’s hand or a velvet stick. The fMRI results revealed that stroking with a hand elicited larger responses than the other experimental conditions in the contralateral primary and secondary somatosensory areas, as well as in the posterior insula. This condition was also the one that gave rise to the highest subjective ratings of pleasantness regarding the stimulation by the participants. The authors suggested that this effect was at least partially mediated by cognitive and emotional correlates of the awareness of being touched directly by another person, rather than by an inanimate object (see also McCabe, Rolls, Bilderbeck, & McGlone, 2008).

A conclusion similar to that reported by Kress et al. (2012) was also reached by Gazzola and her colleagues (2012) in a different neuroimaging study. These authors used fMRI to investigate the neural correlates of social interpersonal touch using actual caresses administered to the shin and calf of their participants’ legs (moving from the knees toward the ankles, with a touch velocity

of ~8 cm/s). These researchers had their participants believe that the caresses were delivered by an attractive woman, wearing a black evening dress and high heels, who behaved in a warm and friendly manner or a man, wearing a black tank top and jeans, who behaved in a rather more distant manner. The images of the caresser were presented by means of video feedback. The results revealed that the activity of S1 was modulated by the visually perceived sex of the caresser. That is, an area of the brain that was thought to be primarily involved in processing the more perceptual aspects of tactile stimuli, also turns out to be involved in the affective processing of social touch (see also Rossetti, Miniussi, Maravita, & Bolognini, 2012, for evidence showing that rTMS over S1 selectively impairs the processing of visual stimuli depicting a human body-part being touched by a human agent but not the visual perception of contact between objects, or between human body-parts and objects). As far as this point is concerned, it is possible that the role of the somatosensory cortex in social and emotional touch was somehow underestimated in previous studies on this topic because C-tactile fibers (responsible for the more hedonic aspects of touch; see Chapter 2) project to, and activate, the insula, but also inhibit the activity of the primary somatosensory cortex.

Unfortunately, very little is currently known about the integration of touch and other sensory inputs (e.g., auditory and visual) that may lead to specific and unique patterns of emotions (see Montoya & Sitges, 2006, for the observation of a modulation of somatosensory-evoked potentials when participants were viewing affective pictures; see also Francis et al., 1999, for the neural correlates of the interactions between pleasant touch, olfaction, and taste). Moreover, one might also question whether one sensory modality can be more effective in activating the brain's emotional neural circuits than the others (and touch, as a function of its relevance for controlling basic body functions and its earlier development, might be the perfect candidate to play a more important role here; cf. Herz & Inzlicht, 2002).

Finally, in this section it is relevant to note that the more emotional and social aspects of tactile sensations may also be related to the functioning of the neural systems responsible for our memory of tactile sensations (see Chapter 6). Indeed, as far as visual stimuli are concerned, it has been shown that participants have a preference for those stimuli that were already presented in a set, even when they were not able to explicitly recognize them as not being novel (e.g., Harrison, 1977; Kunst-Wilson & Zajonc, 1980; Monahan, Murphy, & Zajonc, 2000; Zajonc, 1968). Similarly, we might consider particularly pleasant previously presented tactile stimuli (such as the firm handshake of a friend or the caress of our partner).⁵ Therefore, those areas that are thought to process our memories for tactile stimuli, such as the anterior and ventrolateral prefrontal cortex, the posterior parietal cortex, the perirhinal cortex, the insula and the lateral occipital complex (see Chapter 5) might well be involved in the more social aspects of touch.

Finally, it is worth mentioning that research on the neural substrates of social and emotional touch should also consider individual differences in the population. That is, social contact might be considered more positive in some individuals than in others, thus leading to partially different

⁵ Note that the artist Miho Suganami (see also Chapter 12), has somehow exploited this concept in one of her works titled *Have you touched your hands* (see Spence 2011b). Here, molds were made of the hands of the people living in a small town. After that, Miho made plastercasts of each person's hands. Each pair of plaster hands was then mounted on a wall, and the community invited back to interact with (i.e., touch) them. Miho reports the striking experience of a few people who, on touching a particular pair of hands, suddenly said, "that's my husband," despite the hands being fairly indistinguishable by vision alone.

neural activations when elicited. Consistent with this line of reasoning, Schaefer, Heinze, and Rotte (2012b) recently reported that responses in somatosensory cortices due to tactile stimulation were affected by the personality of the individual receiving the stimulation: The less extraverted the participant, the higher the cortical activity recorded in SI.

7.5 The development of touch as a communication system

The role of touch as a means of interpersonal communication seems to have developed in many different animal species. Indeed, touch is an important form of communication for many animals (see Hertenstein, 2002; Hertenstein, Verkamp, Kerestes, & Holmes, 2006; Moynihan, 1966; Weber, 2005). For example, mother tigers lick and nuzzle their babies, chimpanzees groom each other, and bear cubs wrestle with each other. Even amongst insects, touch can play an incredibly important role. Desert locusts, for instance, transform their behavior from a rarely seen solitary phase to a swarming gregarious phase as a result of reciprocal tactile contact of the hind legs (Anstey, Rogers, Ott, Burrows, & Simpson, 2009). In the animal kingdom, touch is used to comfort, to establish dominance, and to establish bonds. Not surprisingly, therefore, touch seems to be even more important in those species that have been defined as “social animals.” For example, affiliative bodily contact among dolphins, namely “flipper-rubbing,” has been reported to repair weakened relationships or reduce tension within the group following aggressive interactions (see also Tamaki, Morisaka, & Taki, 2006; Terry, 1970).

Similarly, for many primate species living in large groups, inter-individual touch has been shown to help the group form bonds and remain peaceful (e.g., Coelho, Turner, & Bramblett, 1983; Lindburg, 1973; Weber, 2005; see also Coulon, Nowak, Andanson, Ravel, Marnet, Boissy, & Boivin, 2013; Kuhne, Hössler, & Struwe, 2012, for the positive role of touch on the interactions between humans and animals). Primates often groom each other: Female primates often hold and frequently cuddle and comfort their young. What is more, different forms of touch (on different parts of the body) may be used by these animals in order to communicate different meanings (e.g., Boccia, 1986). Following on from these observations, it should come as little surprise that touch plays a very important role as a communication modality in humans as well. Indeed, as pointed out many times in this book (see Chapter 1), touch is the first sense to develop. It has even been claimed by many researchers that interpersonal touch can be characterized as one of humankind’s earliest form of communication (e.g., De Thomas, 1971; Frank, 1957; Knapp, 1972; McDaniel & Andersen, 1998).

Weiss, Wilson, and Morrison (2004) attempted to determine the relationship between early maternal touch and the neurodevelopmental status of low birth weight (LBW) infants. They recorded mothers’ touching behavior during feeding when the infants were 3 months old and then administered neurodevelopmental tests on the same infants at the age of 1 year. The results indicated that those infants whose mothers used more stimulating touch during care-giving had better visual-motor skills at 1 year of age. In addition, the infants of mothers who touched them frequently had more advanced gross motor development. On the basis of these results, Weiss et al. went on to conclude that stimulating and frequent touch may help to compensate for early neurosensory deficits and promote neurodevelopment for LBW infants (see also Field, 2001; Levine, Haltmeyer, Karas, & Denenberg, 1967; Rose, Schmidt, Riese, & Bridger, 1980; Rubin, 1963; Stack, 2001).

Other indirect confirmation of the important role played by interpersonal touch in modulating the well-being of newborn babies comes from studies that have investigated analgesic procedures in infants. Specifically, researchers have investigated the role of different forms of tactile

stimulation on newborn babies having venepuncture or heel prick (a painful procedure; Shaan, 2007—see also Fitzgerald & Gibson, 1984). Shaan showed that the distress caused by venepuncture, heel prick, or immunization can be substantially reduced by use of sucrose 2 min before the procedure, followed by a cuddle plus either breastfeeding or a pacifier given during the procedure (see also Chermont, Falcão, de Souza Silva, de Cássia, Xavier Balda, & Guinsburg, 2009, for a report suggesting that a combination of oral dextrose treatment and skin-to-skin contact can decrease acute pain in healthy neonates). That is, tactile stimulation (including both sucking and being cuddled), appears to interact with other aspects of the stimulation in reducing babies' painful perception (a phenomenon that has been labeled "sensory saturation" and consists of distracting and comforting babies by massaging them, speaking to them, establishing eye contact, using a fragrance and placing 10% glucose on the tongue; see Bellieni, Cordelli, Marchi, Ceccarelli, Perrone, Maffei, & Buonocore, 2007). More generally, massage has also been reported to have a beneficial effect on a number of different aspects of a baby's well-being (e.g., Dieter, Field, Hernandez-Reif, Emory, & Redzepi, 2003; see Underdown, Barlow, Chung, & Stewart-Brown, 2006, for a review).

The results of these studies therefore appear to demonstrate that interpersonal touch plays a crucial role in the development and well-being of humans; but what about the lack of touch? Can the shortage of those tactile sensations that are generally involved in mother–child interactions (such as the perception of the mothers' body softness or warmth by the baby) have a negative effect on psychological development (see Nagasawa, Okabe, Mogi, & Kikusui, 2012, for a review of animal studies addressing this topic)? This topic was first addressed by the pioneering work of Harry Harlow on baby monkeys (see Harlow, 1958; Harlow & Zimmerman, 1959). In a now-(in)famous series of experiments, Harlow removed baby rhesus monkeys from their mothers, and randomly assigned them to one of two possible surrogate mothers, one made of terrycloth, the other of metal wire. In the first group, the terrycloth mother provided no food, while the wire mother did (by means of an attached baby bottle containing milk). In the second group, the terrycloth mother provided food, while the wire mother did not. Harlow and his colleagues observed that the young monkeys clung to the terrycloth mother no matter whether it provided food or not, and that the young monkeys chose the wire surrogate only when it provided food (and they wanted).

Interestingly, whenever a frightening stimulus was brought into the cage, the monkeys ran to the cloth mother for protection and comfort, no matter which mother provided the food. At a later stage of development, the monkeys who had only experienced a wire mother were observed to have trouble digesting milk and suffered more frequently from diarrhea (although note that both groups of monkeys gained weight at the same rate). On the basis of these results, Harlow concluded that not having contact comfort was psychologically stressful to the monkeys. Note, however, that the extension of these conclusions from monkeys to humans by Harlow (together with Harlow's apparent lack of ethical concern for the treatment of his monkeys) has been questioned by a number of researchers in subsequent years (e.g., Cohen, 1996). It therefore seems straightforward to ask what would happen to humans who for whatever reason receive very little tactile contact from their mothers or caregivers (cf. Cascio, 2010, for an association between impaired somatosensory processing and a range of neurodevelopmental disorders).

Several studies have investigated the effect of the deprivation of care at an early age on people's well-being and development. The majority of these studies have investigated the cognitive, social, and neural development of children who have had to live for a certain period of their infancy in substandard institutions for orphans and who, as a consequence, received minimal parental care. These studies have generally reported that the cognitive and social capabilities of these sensorially and socially deprived children are often below the average when compared to same age children

raised in normal families or better institutions (see Maclean, 2003, for a review; see also Chugani, Behen, Muzik, Juhasz, Nagy, & Chugani, 2001; Nelson, 2007; for the possible neural correlates of early deprivation in children). In fact, the consequences of this lack of care can still be apparent years after adoption (e.g., Beckett, Maughan, Rutter, Castle, Colvert, Groothues, Kreppner, Stevens, O'Connor, & Sonuga-Barke, 2006).

Although common sense might suggest that tactile deprivation plays an important role in this outcome, it is important to note that no definitive conclusions regarding the consequences of the lack of interpersonal touch can be drawn on the basis of these observations. Indeed, basic sensory stimulation in institutionalized children can be lacking across multiple sensory modalities leading to the often reported perceptual and cognitive deficits (e.g., children lack patterned light stimulation because walls and ceilings are painted white, leading to a form of visual deprivation; infants are not held or touched, leading to tactile deprivation, and so on; see Nelson, 2007).

Taken as a whole, the results of the research summarized in this section unequivocally suggest that touch can play a very important role in normal human development. In particular, early tactile experiences (even those taking place in the womb) might strongly contribute to shaping and characterizing the emotional, relational, cognitive, and neural functioning of the adult individual. Not surprisingly then, the first object thought to provide a temporal substitute for maternal comfort and a mean to reduce anxiety in babies is a soft one, generally a teddy bear or a blanket (e.g., Winnicott, 1953; see also Dell'Orto, 2003).⁶

7.6 Conclusions

The results of the research reviewed in this chapter have demonstrated that tactile sensations elicited under ecologically valid conditions of stimulation that involve interpersonal interaction can have surprisingly powerful effects on people's behaviors and emotions. Specifically, interpersonal touch appears to be capable of modulating people's compliance with a variety of requests (e.g., Crusco & Wetzel, 1984; Guéguen & Fischer-Lokou, 2003; Joule & Guéguen, 2007). Interpersonal touch can affect people's attitudes toward particular services (e.g., Erceau & Guéguen, 2007; Fisher et al., 1976), it can facilitate bonding between pairs in a couple or groups in both animals and human (e.g., Boccia, 1986; Coelho, Turner, & Bramblett, 1983; Light et al., 2005), and it plays an undeniably important role in people's romantic and sexual relationships (e.g., Frohlich & Meston, 2005a). Unfortunately, though, the research that has been conducted to date has not, as yet, uncovered the reasons why interpersonal touch has such dramatic effects on people, nor do we know all that much about the cognitive, neural, and physiological mechanisms underlying these behavioral phenomena.

In fact, researchers have only just started to address the neural aspects of interpersonal touch by showing that different patterns of brain activation can differentiate between the more perceptual and the more social aspects of tactile sensation (e.g., McGlone et al., 2007; Rolls et al., 2003; see also Rolls, 2010). Interestingly, however, the evidence reviewed here highlights the presence of a profound gap between the majority of research that has been conducted under ecologically valid conditions of stimulus presentation using questionnaire-based procedures and the virtual absence of research that has made use of better controlled laboratory-based conditions of stimulus presentation. Moreover, although a certain amount of research has addressed the physiological

⁶ Interestingly, some captive primates have been observed to keep security blankets just like human babies (see Bloom, 2011, p. 5)

and neural aspects of interpersonal touch, the more cognitive aspects of this topic seem to have been nearly completely neglected by researchers. For example, as yet, we still don't know the characteristics of tactile stimulation that are needed in order for it to be perceived by a person as interpersonal (and eventually pleasant/unpleasant) rather than as mechanical (Auvray, Philipona, O'Regan, & Spence, 2007b; see Spence, 2007b, on this point). The apparent negligence by the research community with regard to this issue might reflect both the relative difficulty of designing experiments in which the topic can be properly assessed (also because of possible ethical concerns that might constrain experimentation in the field) but also a lack of robust theories waiting to be tested.

Answering these questions will be of vital importance not only from a theoretical point of view, but also from an applied perspective. Indeed, we have seen that technical innovations have allowed us to communicate more interactively and at virtually no cost with people who may be many miles away from ourselves. Unfortunately, however, these new forms of communication have not, as yet, included tactile contact. A few major problems appear to have constrained this choice in the past; one undoubtedly relates to technical limitations. That is, more complex forms of communication require higher bandwidth and computational capacity, which have not been available to researchers in this field previously (see, for example, the lag problem that constrained the use of the arm wrestling device developed by White and Back, in 1986; see also Marescaux, Leroy, Gagner, Rubino, Mutter, Vix, Butner, & Smith, 2001). Now that both bandwidth and computational power would appear to constitute less of a limitation than they were previously, other more theoretical problems are coming to assume a more important role. Specifically, technological innovation seems to require greater theoretical advances in research into the nature of interpersonal touch before it can produce results that are fully applicable.

We believe that even the most advanced devices will not be able to deliver something that can approximate to realistic interpersonal touch if we don't know in the first instance what needs to be communicated and how to communicate it. Specifically, what is the role played respectively by caloric, kinesthetic, proprioceptive, motion, and vibratory cues in informing us of another human being touching our skin/body? Furthermore, how can tactile sensations be mechanically reproduced if we still lack a proper and shared lexicon of touch (i.e., a classification of tactile sensations; see Spence & Gallace, 2008, for a discussion on this point; see also Guest, Dessirier, Mehrabyan, McGlone, Essick, Gescheider, Fontana, Xiong, Ackley, & Blot, 2011, for an attempt to build such a lexicon)? So far, it seems to us that our knowledge concerning tactile perception is still at a relatively early stage of development that does not allow for highly complex forms of long-distance realistic interpersonal tactile communication to be fully effective (and emotionally fulfilling). Nevertheless, the attempts that have been made so far to add simple forms of tactile interpersonal interactions to long-distance communication seem to be very promising. We believe that it is only when touch is fully integrated in VR environments and Internet technologies that our experience as users of communication-devices will be truly complete and immersive (see Hoffman et al., 1998; Lin & Otaduy, 2008; see Chapter 9). Not surprisingly, research in the field of teleoperator systems is now moving faster and faster in order to achieve this important goal (e.g., see Gallace et al., 2007a, for a review).

The present chapter has revealed a nearly complete lack of research regarding how the tactile aspects of tactile communication interact with visual, auditory and olfactory aspects of our environment. That is, in everyday situations, tactile stimulation never occurs in isolation as a form of interpersonal communication (at least for individuals who are not visually or auditorily impaired; see also Finnegan, 2005). Touching your spouse's hand, smiling and saying "I love you" sounds very different than touching her/his hand and saying "Dinner is ready!" But does it also "feel"

different? The rather disappointing answer from the extant tactile research is that we simply don't know! That is, research cannot tell whether, within an interpersonal context, tactile sensations can be modulated by visual and auditory information that is concurrently presented (though see McCabe et al., 2008, for one attempt to address this topic; see also Montoya & Sitges, 2006). Although laboratory-based research on tactile perception clearly suggests that this might be the case (see Rolls, 2010), these questions should be addressed within the domain of interpersonal touch as well (for example, by evaluating the pleasantness of an interpersonal tactile stimulus, such as a stroke, when presented together with either a happy or angry face/voice). That is, future research will need to investigate whether or not visual information dominates in the domain of interpersonal touch (e.g., Hartcher-O'Brien, Gallace, Krings, Koppen, & Spence, 2008; Spence, 2007b) also within an interpersonal context and how we integrate visual, auditory and tactile cues in processing (and making sense of) interpersonal information.

On the basis of the results of those studies that have investigated the more perceptual aspects of multisensory interactions, a number of different integration strategies can be used by participants as a function of the specific conditions of stimulus presentation (see Ernst & Bühlhoff, 2004, for a review). It might also be the case that the degree to which vision or haptics dominates the social aspects of our behavior is related to a principle of "optimization" that takes into account the variability of the different input signals (e.g., Ernst & Banks, 2002; see also Jansson-Boyd & Marlow, 2007). That is, people might weight the social signals from different sensory modalities as a function of their reliability and then combine them in an optimal fashion (see Argyle & Dean, 1965). Note that, as far as social interactions are concerned, the role of the context and of previous social experiences might provide further variables that need to be added to the model. In summary, the research outlined in this chapter has highlighted the importance of the more interpersonal aspects of tactile communication for our well-being, as well as to the lack of any integrated framework for the knowledge on this topic arising from different domains. The research has demonstrated that cultural, perceptual, and neurophysiological factors all need to be considered in order to have a more complete picture of the sense of touch when used within an interpersonal relationship. As a consequence, we believe that further theoretical and applied advances in research on this fascinating topic will be possible only by means of a greater synergy of efforts from different research fields. In Chapter 8, we will discuss the role of tactile stimulation in the representation of our body and how this representation might adapt to even important changes to body anatomy.

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Outside the boundaries of our bodies: The relationship between the sense of touch and the representation of the body in our mind

A dismayed man never entirely loses the feeling of his old spar . . . And I still feel the smart of my crushed leg, though it be now so long dissolved.

(Melville, Moby Dick, 1851, p. 467)

Anything which participates in the conscious movement of our bodies is added to the model of ourselves and becomes part of those schemata: a woman's power of localization may extend to the feather of her hat.

(Head & Holmes, 1911, p. 188)

8.1 Introduction

Just as we saw in Chapter 2, our somatosensory system spreads over our entire body surface, providing information about external stimuli that impinge on our skin, but also about the current status of our body and its internal organs (e.g., Björnsdotter, Morrison, & Olausson, 2010; Craig, 2003). That is, our sense of touch is heavily linked to our body in a way that no other sensory system is. In some ways, our sense of touch marks the territory of what is “us” and what is not. Following on from such considerations, it seems clear that localizing somatosensory sensations becomes a relevant factor in the discrimination of where our body begins and where it ends. Intuitively, from a naïve point of view, the question of where our body ends or even about whether or not a certain object is actually part of our body might appear trivial or purely speculative. That is, most people are convinced that their body parts are in fact their own, and there is no point in discussing the topic (see Gallagher, 2000, for a discussion on the concept of body ownership). However, from a more scientific point of view, this matter is much more complex than one might, at first, realize. Why should we recognize our body but critically no other objects as something that belongs to our self? How does our brain cope with this difference? In fact, researchers have consistently demonstrated that our sense of body ownership, the perception that our body (and the parts that compose it) belongs to us, can sometimes easily be modulated and that external objects can be perceived by neurologically normal participants as part of our body, just as actual

parts of our body sometimes appear not to belong to us. One might think, for example, of wedding rings, or even hats (as the quote at the beginning of this chapter would seem to suggest), that are often considered as actual parts of our body. By contrast, fingernails that are an actual part of our body can even be voluntarily removed, whenever we cut them, without any psychological consequence. These kinds of phenomena can also occur in some clinical conditions, where the sense of ownership over our body, or at the very least parts of it, can be lost (e.g., Fotopoulou, Jenkinson, Tsakiris, Haggard, Rudd, & Kopelman, 2011; Moseley, Gallace, & Spence, 2012a; Sedda, 2011).

In our everyday lives, we do not normally constantly feel the presence of the clothes we happen to be wearing on our skin. Sometimes, though, when we remove our glasses or cap after a long period of time wearing them, we still temporarily feel their presence. Similarly, operators of human-machine interfaces, such as surgeons, who are used to performing complex robotic operations (a procedure utilized in order to increase the precision of surgical operations, with very positive consequences on patients' recovery time and hospitalization; see Chapter 9), often report the feeling that the machine becomes like an extension of their own body. That is, in many situations, people can perceive that their sense of ownership extends to external objects. Some controversial modern artists have even made these incorporations, or attempts at incorporations, of objects into their body, their artistic signature. For example, the Australian artist Stelarc (<<http://stelarc.org/?catID=20247>>; downloaded on October 12, 2012) added a number of prostheses, comprising hands, head, and even an extra ear to his body in order to explore the limits of the relationship between the self and external objects (see Figure 8.1).

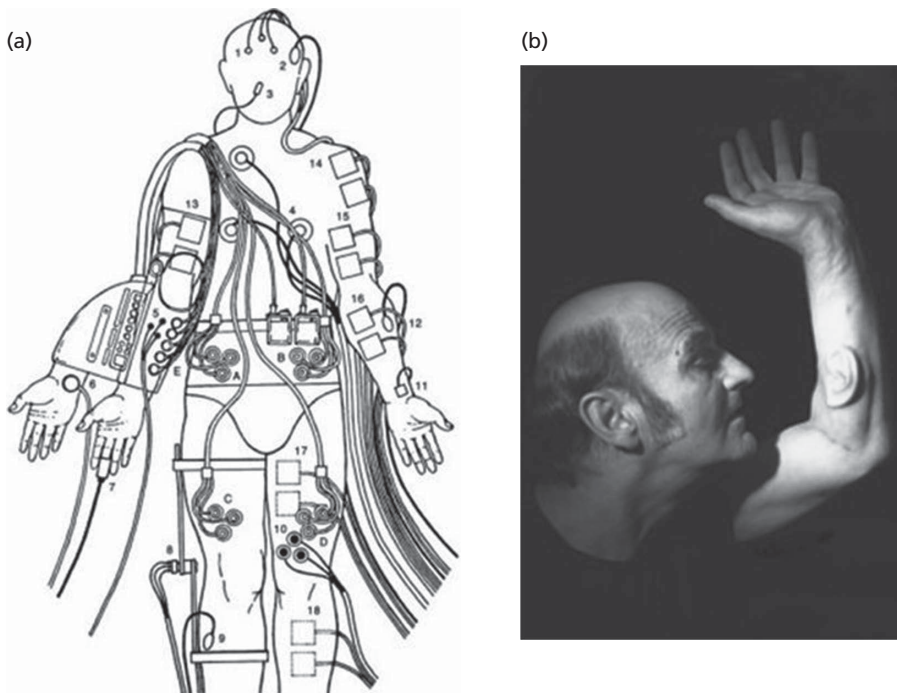


Fig. 8.1 (a) Representation of a human-robotic third hand from the website of the artist Stelarc. (b) A photograph of Stelarc showing his arm with a cell-cultivated ear surgically inserted into it. Reproduced with permission from <<http://stelarc.org/media/img/bio-img.gif>>.

The fact that our brain is prepared to integrate in its own circuits additional body parts that are not an anatomical product of genetic coding opens up intriguing possibilities as well as a number of theoretical, philosophical, and even ethical questions. In particular, one might wonder what the neurocognitive bases of our sense of bodily self really are? Should human beings be allowed to artificially modulate the main structure of their body and its organic interfaces in order to achieve novel functionality (or to perform old functions more efficiently), considering that that structure has so far been the best possible result of thousands of years of human evolution? Can technological evolution supersede natural evolution of the human species? The questions that arise from the study of body ownership are certainly endless, but in order to provide answers to many of them the study of this important topic should be further extended in the coming years.

In this chapter, we will describe the research that has demonstrated that body ownership can be modulated by using simple procedures in both real and virtual environments. In particular, we will demonstrate that people can “own” virtual prosthesis and even full-body avatars. Next, evidence regarding the possibility of manipulating the perception of one’s body size without modifying one’s actual body will be outlined. In the final sections of this chapter, the neurological basis of body ownership and the relationship between alterations of this function and the homeostatic control of the organism will be addressed. In particular, we will demonstrate that whenever a person perceives an artificial object as part of his/her own body, physiological changes will also occur to their own body’s functioning. A neurocognitive model capable of explaining the occurrence of many of these changes, “the body matrix,” will also be outlined. The chapter will show that the sense of touch is of great importance in terms of the occurrence of modulations of body ownership, but that the study of multisensory integration of tactile, visual, and proprioceptive information is certainly the key to better understanding, and eventually exploiting, these fascinating phenomena.

8.2 The rubber hand illusion: When artificial objects become a part of us

Many years have passed since Tastevin (1937) first reported that people mistake a plastic finger protruding from a cloth as their own finger when the latter was, in fact, concealed under a cloth several centimeters away. For many years, this phenomenon did not attract the interest of researchers, until, that is, Botvinick and Cohen (1998) published their now-famous work on the “rubber hand illusion” (RHI). As mentioned in Chapter 4, in the classic RHI paradigm, participants are seated with one arm resting on a table, out of view behind an occluding screen (or else covered by a cloth). An artificial rubber hand can be seen directly in front of the participant, normally in a posture that is similar to that of the occluded hand (see Figure 8.2). The experimenter then starts to stroke the rubber hand and the participant’s occluded hand in synchrony. Remarkably, after just a few seconds of stroking, the majority of participants start to report feeling that the tactile sensations resulting from the stroking of the rubber hand are coming from their real hand (Botvinick & Cohen, 1998). Importantly, the RHI not only affects the way in which we perceive our body as belonging to us, but also to the way in which our brain reacts to possible danger to what is considered “its” body. Threatening the rubber hand (i.e., with a sharp needle) after having induced the illusion, for instance, will result in enhanced activation being seen in those brain areas associated with anxiety and interoceptive awareness (the insula and anterior cingulate cortex). This activation is similar to that seen should the person’s actual hand be threatened. Moreover, the stronger the feeling of ownership over the artificial hand, the stronger the neuronal

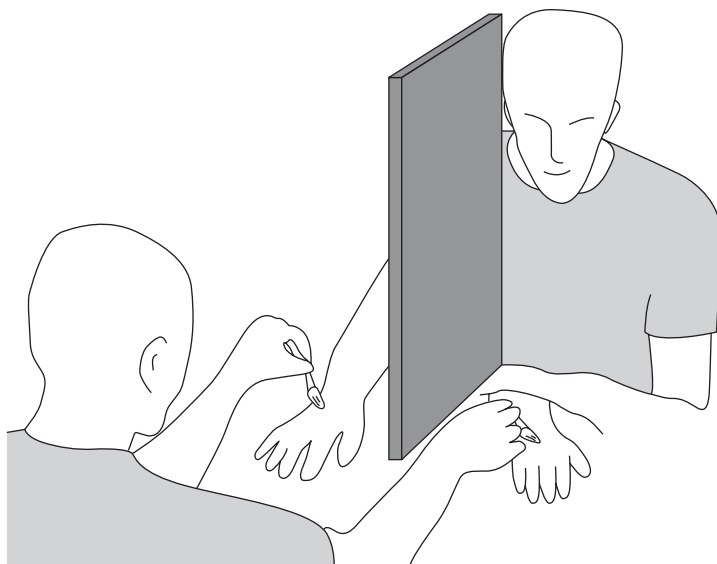


Fig. 8.2 Setup often used to induce the RHI.

responses in the areas reflecting anxiety (e.g., Armel & Ramachandran, 2003; Ehrsson, Wiech, Weiskopf, Dolan, & Passingham, 2007; Lloyd, Morrison, & Roberts, 2006).

Somatosensory information and multisensory integration would seem to be crucial for the elicitation of the RHI. In fact, the illusion works best when tactile and visual information are temporally consistent (that is, when the stimulation of real and artificial arm is synchronous). Note, however, that the illusion can also sometimes be elicited even in the absence of any stroking (of either the real or rubber hand), providing, that is, that the real and fake hand are approximately aligned (e.g., on the vertical plane; see Pavani, Spence, & Driver, 2000; Walton & Spence, 2004). That is, an approximate anatomical compatibility between the visually perceived position of the rubber hand and the position that the participants arm seem to be an important factor contributing to the elicitation of the RHI.

The congruency between the kind of stimulus delivered to the rubber hand and to the real hand is important, but secondary to the illusion. In fact, Durgin et al. (2007) demonstrated that when the light of a laser pointer is shined on the rubber hand in synchrony with the presentation of a tactile stimulus to the participant's own hand, then an illusion was induced in 66% of the participants that they tested (e.g., Durgin et al., 2007). By contrast, purely visual information, such as similarities between the rubber hand and the participant's real hand do not seem to play a role in terms of inducing the illusion (e.g., Armel & Ramachandran, 2003; Hohwy & Paton, 2010; see Farmer, Tajadura-Jiménez, & Tsakiris, 2012, for the possibility of eliciting the illusion even when the rubber hand is of a different color to the participants' own skin). In fact, Armel and Ramachandran reported that neurologically normal participants could perceive tactile sensations as arising from a "table" when both the table and their own real hidden hand were synchronously tapped and stroked (see also Hohwy & Paton, 2010; cf. Holmes, Snijders, & Spence, 2006, for evidence suggesting that even a piece of wood can sometimes induce proprioceptive drift—that is, a shift in the localization of the participant's real limb).

Not only is congruency between visual and tactile information effective in eliciting the RHI, the simultaneous presence of consistent tactile and proprioceptive signals is sufficient to induce

the illusion. In particular, Ehrsson, Holmes, and Passingham (2005) tested whether the RHI could be induced in blindfolded participants. In their study, the experimenter moved the blindfolded participant's left index finger and made it touch an artificial right hand. Simultaneously, he/she touched the participant's real right hand on the same position touched by the left finger. Under such conditions, the illusion that the participant was touching his/her own hand was induced after just under 10 seconds from the start of stimulation (pretty much the same time required to induce the illusion using the standard visuotactile procedure). Here, it should be noted that while this form of tactile stimulation is very effective in inducing the illusion in blindfolded participants, the very same procedure is completely ineffective in terms of inducing the illusion in blind participants (Petkova, Zetterberg, & Ehrsson, 2012). Petkova et al. suggested that this might be due to the fact that blind individuals have a more veridical percept of self-touch and a less flexible and dynamic representation of their own body in space as compared to sighted individuals.

Interestingly, illusions of ownership can also be obtained in amputated patients while using an advanced hand prosthesis, even when they have a robotic-like, rather than a more natural appearance (Rosén, Ehrsson, Antfolk, Cipriani, Sebelius, & Lundborg, 2009). In this case, the illusion is elicited by providing simultaneous tactile stimulation to the hidden amputated stump and to the prosthetic robotic hand placed in full view. Finally, it is not only possible to induce the illusion that one limb has been replaced by an artificial one but also that an additional "supernumerary" limb is connected to our body (e.g., Schaefer et al., 2008; thus mimicking the condition of certain patients suffering from body representation disorders; e.g., Aimola Davies & White, 2011; Cipriani, Picchi, Vedovello, Nuti, & Fiorino 2011). That is, our brains can be tricked into believing that additional limbs, or even inanimate objects, are part of our anatomies.

8.2.1 Enfacement

Illusory variations of our sense of body ownership are not limited to peripheral body parts such as the hands, but extend to other body regions including the face, an highly distinctive body part that profoundly contributes to our feeling of self-identity (Sforza, Bufalari, Haggard, & Aglioti, 2010; see also Apps, Tajadura-Jiménez, Turley, & Tsakiris, 2012, for the neural mechanisms related to self face recognition and ownership over the life span). Sforza and his colleagues touched the face of their participants who were viewing simultaneous synchronous or asynchronous touches on a partner's face (the face of a person of the same sex as the participant, and someone who was familiar to him/her). Then they had participants judge the extent to which a morphed image obtained by mixing the picture of the participant's face with that of the partner represented themselves or the partner (i.e., they had to respond on a visual analogue scale anchored to 0 and 100 points, to questions such as the following: "How much does the image represent yourself?" where 0 corresponded to "other" and 100 to "self"). In addition to this task, the participants had to rate their degree of agreement with a number of statements, that were adapted from the study on the RHI described by Botvinick and Cohen (1998). This questionnaire contained to-be-rated items such as: "It seemed as if I were feeling the touch of the paintbrush in the location where I saw the other's face touched" or "I felt as if the other's face was my face." They found that only after asynchronous stimulation did the participants rate the morphed images of themselves and their partner as containing more self than other. Moreover, the results of the experiment revealed more agreement amongst the participants with the statements that indicated the development of a face-related illusion of ownership (that the authors named "enfacement"). Sforza and his colleagues concluded that even the sense of facial identity may be more malleable than previously thought

(see also Cardini, Tajadura-Jimenez, Serino, & Tsakiris, 2012; Tsakiris, 2008, for other experiments on enfacement).

Interestingly, Sforza and his colleagues reported that the illusion of enfacement correlated positively with the participant's empathic traits related to perspective taking (i.e., the ability and tendency to adopt the point of view of another individual) and empathic concern (that is, the tendency to share others' emotions and feelings). Moreover, the strength of the illusion was also modulated by the degree of physical, but critically not inner, attractiveness attributed to the partner. Speculatively, this might suggest that enfacement becomes increasingly likely the more the individual would like to look like the other person. This is something that will definitely need to be assessed more accurately in future research. It is also important to note that Sforza et al.'s (2010) results were obtained by presenting faces of same-sex and already-known individuals, therefore, one may wonder whether enfacement might also occur toward faces belonging to complete strangers, toward people of a different race, or even toward faces having a different gender (see Farmer et al., 2012).

8.2.2 The full-body illusion and the abandonment of one's own body

Thus far, the research reported in this chapter has demonstrated that people can perceive artificial prosthesis, external objects, and even, at least up to a certain extent, other people's faces as actual parts of their own body. However, is it possible to go even further and extend our sense of body ownership to entire bodies? An answer to this question comes from those studies that have investigated a phenomenon known as the "out of the body experience." These can be described as experiences in which a person who is awake sees his or her body from a location outside the physical body, without the presence of an actual visual stimulus (e.g., Blanke, Landis, Spinelli, & Seeck, 2004). These experiences have been reported in a number of clinical conditions such as following stroke, partial epileptic seizures, and drug abuse, as well as sometimes in neurologically normal participants in those periods of time that immediately precede and follow sleep (e.g., Blackmore, 1984; Blanke et al., 2004; Brugger, 2002; see also Giummara, Gibson, Georgiou-Karistianis, & Bradshaw, 2008). A typical example of this phenomenon can best be illustrated by quoting a patient experiencing it: "Suddenly it was as if he saw himself in the bed in front of him. He felt as if he were at the other end of the room, as if he were floating in space below the ceiling in the corner facing the bed from where he could observe his own body in the bed . . . he saw his own completely immobile body in the bed; the eyes were closed" (Lunn, 1970, p. 122; see also Blanke & Arzy, 2005).

Ehrsson (2007) first demonstrated that out of the body illusions can also be induced in healthy participants using procedures that are similar to those adopted to induce the RHI (see also Brugger, Regard, & Landis, 1997). Participants in his experiment sat on a chair, wearing a pair of head-mounted displays that were connected to video cameras placed 2 meters behind the participant's back such that the person would see his or her back with the perspective of a person sitting behind him or her. The experimenter simultaneously touched the participant's actual chest, which was out of view, and a position corresponding to the chest of an illusory body placed in front of the camera using two plastic rods. The latter was achieved by moving one rod toward a location just below the cameras. Synchronous and asynchronous visuotactile stimulation were then delivered. During asynchronous stimulation, the participants reported the experience of sitting behind their physical bodies and looking at themselves from this location. Moreover, their physiological reactions, as indexed by means of their skin conductance responses to a threat (seeing a hammer hitting the body) to the illusory location of their body were analogous to those seen when their

real body was threatened (even if these automatic reactions were likely lowered as compared to those occurring under a more realistic and ecologically valid environment). That is, participants can easily be tricked into perceiving that their own body is located outside its physical boundaries! Once again, this illusion can be obtained by using consistent visual and tactile information, just as in the RHI.

In another study, Petkova and Ehrsson (2008) had their participants watch the body of a mannequin being touched from a first-person perspective while simultaneously being touched by a rod on the same position of their own abdomen. The results demonstrated that during synchronous visuotactile stimulation, that is, when the mannequin and the participant's body were touched simultaneously, the participants could feel that the mannequin's body was their own body, and that they perceived the touch of the rod directly on the mannequin's abdomen. They also reacted to a threat to the mannequin with an appropriate physiological reaction (in terms of variations in the skin conductance response), just as in previous experiments by the same research group (see Ehrsson, 2007).

Petkova and Ehrsson (2008) went even further in their research by substituting the mannequin with a real person, with the aim of inducing a "body-swapping" illusion. In this further study, the experimenter wore a helmet equipped with two cameras mounted in such a way that they presented the viewpoint of the experimenter (see Figure 8.3). The participants stood directly opposite the experimenter (directly facing the cameras), wearing a head-mounted visual display connected to the experimenter's cameras. The participants had to stretch out their right arm and repeatedly squeeze the experimenter's hands for 2 minutes. The squeezing of the hands could either be synchronous or asynchronous (in the latter case, the experimenter returned the squeeze in a semi-random manner rather than at the same time as the participant's squeeze). By means of such a procedure, the synchronous stimulation evoked in many of the participants was the illusion that the experimenter's arm was their own. Moreover, the illusion of ownership (also confirmed by the results of physiological reactions to threat stimuli) extended to the rest of the body so that the participants could sense the entire body just behind the arm as belonging to them.

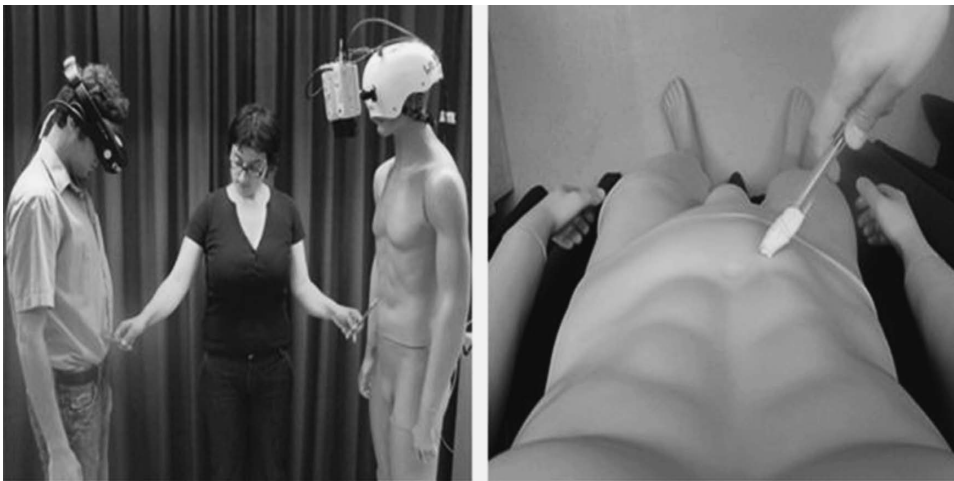


Fig. 8.3 Experimental setup adopted by Petkova and Ehrsson (2008) in their study. Data from V. I. Petkova, and H. H. Ehrsson, If I were you: perceptual illusion of body swapping, *PLoS ONE*, **3**, e3832, 2008.

Even more surprisingly, those sensations elicited by the squeezing of their hands were reported by the participants as originating from the experimenter's hand, and not from their own hand, even if the latter was fully visible to them. That is, they perceived that their body had, in some sense, been swapped with that of the experimenter!

Interestingly, the full-body ownership illusion can be successfully adopted to reduce the impact of certain clinical conditions such as phantom limb pain (a phenomenon experienced by many amputees where the patient perceives that the amputated limb is still attached to the body and hurts; e.g., Giummarra & Moseley, 2011; note that phantom limbs can also be experienced by the rare individuals who have been born without limbs; see Melzack et al., 1997). Pain in phantom limb patients is often associated with “telescoping”—that is, the perception that the phantom limb gradually retracts inside the remaining stump. By using the same procedures as those adopted by Petkova and Ehrsson (2008), Schmalzl, Thomke, Ragnö, Nilseryd, Stockslius, and Ehrsson (2011), recently demonstrated that by inducing an illusion of full-body ownership, telescoping sensations could be temporarily removed in upper limb amputees. That is, the illusion that we own a different body would seem to be beneficial for those conditions in which the physical body has been damaged and has lost some of its functionality, as in the case of amputees.

In this section, the evidence that has been reported has unequivocally highlighted the fact that people can easily perceive that they own an external body or that their own body is placed in a different spatial position with respect to their real one. One might, however, wonder about what happens to their sense of ownership over their own body during the occurrence of these phenomena. Guterstam and Ehrsson (2012) investigated this issue by inducing in their participants the illusion that they were located in a different place from their real body. The procedures adopted in their study were the same as those used in the study by Ehrsson (2007) discussed earlier. These researchers reported that during the illusion many of the participants reported that they disowned their own body. In particular, their physiological reactions to a perceived threat to their own body were reduced when the illusion was induced (that is, when visuotactile synchronous stimulation was delivered) as compared to the condition in which no illusion was induced (i.e., when asynchronous visuotactile stimulation was presented). That is, not only can participants feel that their body is located in a position where no physical body is actually present, but they also start to feel that their own body belongs less to them, as a consequence of this manipulation.

8.3 Illusory modulation of body size (or the quickest way to lose weight!)

The integration of tactile and proprioceptive information may not only result in changes to our sense of ownership regarding a certain body part but also to a distorted perception of the size and proportions of our own body. It turns out that information from the somatosensory system is very important in terms of maintaining the correct perception of the size of our very own body. Note that inducing complete anesthesia of the thumb by means of digital nerve block gives rise to a significant increase in the perceived size of that body part (by around 60–70%). Similarly, inducing a sensory loss in the lips using a topical anesthetic also results in a significant increase in the perceived size of this part of the body (e.g., Gandevia & Phegan, 1999; see also Paqueron, Leguen, Rosenthal, Coriat, Willer, & Danziger 2003, for similar results obtained after upper limb, lower limb, or spinal anesthetic blocks). Most of us (excluding a lucky few) have likely experienced just these kinds of sensations when seated on the dentist's chair! Importantly, not only can

the reduction of sensory stimulation result in an alteration of perceived body size, an increase of stimulation might also produce similar results. In fact, it has been demonstrated that an elevation of peripheral inputs, obtained by the innocuous electrical stimulation of the digital nerves or the painful cooling of the digit significantly increases the perceived size of the stimulated body parts (e.g., Gandevia & Phegan, 1999).

The simultaneous presence of incongruent proprioceptive and tactile signals often results in amazing changes in the perception of size of the body. In particular, it is well known that when the body or tendon of a muscle is mechanically vibrated (e.g., at around 100 Hz), the muscle reflexively contracts (e.g., Hagbarth & Eklund, 1966). However, if the motion of the limb is prevented, an illusory motion of the stationary limb may be experienced (e.g., Goodwin, McCloskey, & Matthews, 1972). Moreover, whenever the limb comes into direct contact with another body part, such as the nose, the participants not only feel that the vibrated limb is bending, but also that the other body is becoming elongated or else that it shrinks (see Lackner, 1988, for a large number of examples of these distortions). This phenomenon is known as the “Pinocchio illusion,” and has been attributed to the necessity of the brain trying to maintain a coherent representation of the body in which it finds itself (see Figure 8.4). That is, if proprioceptive information from the muscles of the biceps tells us that our arm is stretching, and if information from the somatosensory system tells us that our hand is touching our nose, the only possible synthesis (even if logically absurd) of these sources of information that preserves the integrity of the body (as an alternative to the perception that our nose has become detached from our face), is that our nose elongates, just like in the character invented by Carlo Collodi in his famous 1883 novel *The Adventures of Pinocchio* (see Figure 8.5).

Ehrsson and his colleagues (Ehrsson, Kito, Sadato, Passingham, & Naito, 2005) adopted a particular configuration of the Pinocchio illusion in order to study the neurological bases of effects

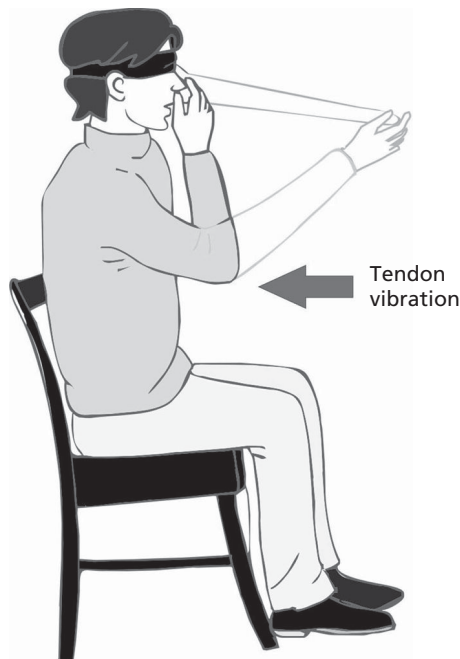


Fig. 8.4 An example of the setup adopted to reproduce the Pinocchio illusion with the corresponding perception from the participant experiencing it.

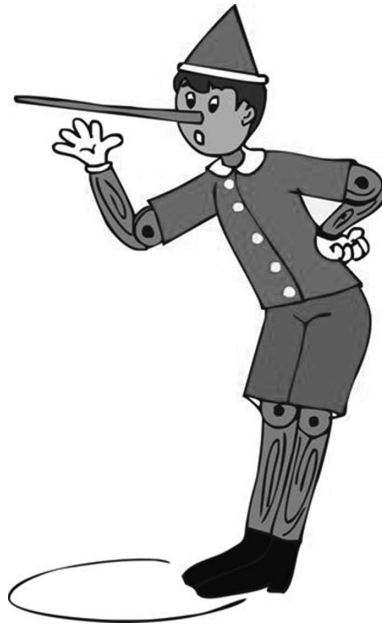


Fig. 8.5 The fictional character “Pinocchio” by Carlo Collodi.

of body size perception in neurologically normal participants. They had participants place their hands such that their palms were in direct contact with their waist and hips. Next, they vibrated the participants’ tendons attached to the wrist extensor muscles, leading to the feeling that the hands were bending inwards. This configuration also led to the illusion that the participants’ waist and hips were shrinking. In particular, when instructed to select a picture out of six pictures showing different conceivable body-image distortions, all of the participants selected the picture showing the shrinking waist. Moreover, a measure of the extent of the illusory effect revealed that the participants perceived their wrists flexed by $13.6^\circ \pm 7.5^\circ$, corresponding to a 28% reduction in the size of their waist.

Ehrsson and his colleagues also scanned their participants’ brains using functional magnetic resonance imaging and found that the illusory shrinkage of the waist led to activity in the cortices lining the left postcentral sulcus and the anterior part of the intraparietal sulcus. That activity was correlated with the perceived amount of shrinking. On the basis of these results, they concluded that the perception of changes in body size is mediated by higher-order somatosensory areas in the parietal cortex. Note that these areas have been shown to be important in the maintenance of a coherent body representation (e.g., Ehrsson et al., 2005a).

8.4 Virtual bodies in virtual words

Technology now allows for the creation of artificial counterparts to our self or at least to a part of it within a machine-controlled virtual environment (see Chapter 9, for a discussion on this point) and to make them interact with objects as well as with other people (see Pan, Gillies, Barker, Clark, & Slater, 2012). This advance creates the opportunity to test whether or not illusions of

ownership can also extend to virtual body parts, to entire body avatars, and even to non-human bodies (such as robots, animals, etc.). The possibilities of a machine-controlled virtual environment are certainly endless, and one might also imagine the creation of bodies with additional limbs or even with extensions to be utilized for specific tasks (something that we might call “functional virtual prosthesis”). What then does the research tell us about these intriguing possibilities? Is it possible to extend the sense of body ownership to virtual limbs or bodies, just as has been demonstrated for real artificial prostheses? Is our brain prepared for these “embodiments” to occur? The answer to these questions would appear to be “yes.”

In 2008, for the very first time Slater, Perez-Marcos, Ehrsson, and Sanchez-Vives created the illusion of the ownership of a VR arm. In order to manage this feat, they delivered tactile stimuli to a person’s hidden real right hand and synchronous virtual visual stimuli to an aligned 3D stereo virtual arm projecting horizontally out of the participant’s shoulder. The participants experienced a displacement of body ownership toward the virtual hand measured through questionnaire procedures as well as through proprioceptive drift. (Note that illusions of ownership result into a mislocalization of the real arm toward the position of the “embodied” artificial arm; see Tsakiris et al., 2007.)

Importantly, though, virtual arms situated within a virtual environment do not need to be aligned with the participant’s body in order to induce an illusion of ownership. In fact, it has been demonstrated that the illusion of ownership toward a virtual arm can be induced even when the real and the artificial hand are not spatially aligned (Perez-Marcos, Sanchez-Vives, & Slater, 2012). By contrast, the perceived connectivity between the arm and the rest of the virtual body, together with synchronous visuotactile stimulation appear to be the key factors in terms of inducing the illusion within such a setting. Researchers have also demonstrated that very long virtual arms (that is, arms that are disproportionately long with respect to the size of the body) can still be perceived as part of a participant’s body within a VR setting (Kilteni, Normand, Sanchez-Vives, & Slater, 2012; see also Tajadura-Jiménez, Väljamäe, Toshima, Kimura, Tsakiris, & Kitagawa, 2012, for evidence suggesting that the perception of body length may also be affected by the sound of one’s action within a given environment). That is, the plasticity of our neural system allows for the incorporation within our body representations of virtual objects or prosthesis that even break the more conventional rules of human anatomy! Although it should be reckoned that the extent of these violations and the existence of insurmountable boundaries that prevent these modulations from occurring (e.g., such as the presence of connectivity between different virtual body parts) has still to be fully tested. Thus far, we know that the classic RHI works best when the fake hand is placed within the limits of peripersonal space (that is, the space that we can reach directly with our own body; see Lloyd, 2007), but we do not know whether these kinds of limitations also extend to virtual environments, especially if one considers that peripersonal space might be artificially extended in VR.

Finally, one last point that ought to be addressed by researcher relates to the fact that not everybody is affected by illusions of body ownership, such as the RHI. So what makes people different in terms of their ability to report sensations from artificial or virtual hands, limbs, or even tools? And how might these individual differences affect the way in which we interact with virtual environments? A study by Tsakiris, Tajadura-Jimenez, and Costantini (2011) demonstrated that people’s interoceptive sensitivity—that is, their ability to perceive signals as coming from their own body—predicts the malleability of the representation of their own body. That is to say, those participants who were less able to monitor an interoceptive signal, such as their heart-beat, experienced a stronger illusion of ownership over an artificial rubber hand.

8.4.1 From male to female with the click of a mouse

Slater, Spanlang, Sanchez-Vives, and Blanke (2010) directly tested the possibility of extending our sense of bodily ownership to all-body virtual avatars situated within a virtual environment (see also Olivé & Berthoz, 2012, for a similar study). The researchers created a simulation of a 3D room, fitted out with a few pieces of furniture comprising a sofa, a table, a chair, a bookshelf, a TV screen, and a mirror. Within this environment, they also simulated an avatar representing a female body (see Figure 8.6). Slater and his colleagues tested the effect of three different variables on the participant's sense of ownership over the avatar: perspective, movement, and touch. In order to test the role of perspective, the participants could see through the eyes of the avatar (first-person perspective) or they could see the scene from a point of view situated 1 meter to the left of the avatar (third-person perspective). The role of movement was tested by synchronously or asynchronously aligning the movement of the avatar with that of the participant. Finally, the effect of touch was investigated by presenting an additional character representing a girl within the virtual scene, either synchronously or asynchronously stroking the avatar's shoulder. The results revealed that an illusion of ownership toward the avatar (measured by a questionnaire and the heart-rate deceleration elicited by a threat to the virtual body) could be elicited in the participants and that the most important factor driving this illusion was the presence of a first-person perspective. Interestingly, visuotactile synchrony was not found to be critical for the ownership illusion to develop (see Pavani et al., 2000, for evidence showing that the classic RHI can also be induced without visuotactile synchronous stroking). It is, however, important to remember that the participants were not required to look continually at the actual



Fig. 8.6 The virtual reality setup adopted in Slater et al.'s (2010) study of body ownership. Reproduced from M. B. Slater, M. Spanlang, M. V. Sanchez-Vives, and O. Blanke, First person experience of body transfer in VR. *PLoS ONE*, **5**, e10564, 2010.

point of contact between the virtual hand and the shoulder, such as in the RHI in Slater et al.'s experiment. Therefore, one might wonder whether the lack of direct observation of touch might have reduced the impact of visuotactile synchrony in inducing the illusion. In summary, Slater et al. demonstrated that body ownership can extend to virtual avatars in virtual environments. Importantly, the gender of the avatar used by Slater and his colleagues in their experiment was feminine while all of the participants were male, thus suggesting that you really can change gender at the click of a mouse!

The results of the experiments reported so far in this chapter clearly suggest that the resemblance of the virtual body to the real body and even the congruity of gender are between them are not that relevant for the sense of ownership over the avatar to develop. As far as the point about the similarity between the real body and the avatar's body is concerned, experiments have demonstrated that participants can even change the representation of the appearance of their own body as a function of the appearance of the avatar's body. In particular, Normand, Giannopoulos, Spanlang, and Slater (2011) immersed their participants in a VR setting where their own body was substituted by a virtual counterpart of it (in this case, larger than the participant's actual body). The presentation of synchronous multisensory stimulation resulted in the illusion that the participants were significantly "fatter" than they actually were (see also Farmer et al., 2012, for evidence showing that people can experience body ownership over hands that seem to belong to a different racial groups, thus suggesting that the mechanisms of multisensory integration in body ownership can override the more semantic aspects of cognition).

8.5 The relationship between body and mind: Physiological consequences of modulations of body ownership

For centuries, philosophers and scientists have debated the question of the relationship between mind and body, where even the strongest supporters of a distinction between the two, such as René Descartes¹ (see Figure 8.7), have often claimed that a very powerful and strong link exists. The discovery and following scientific investigation of the RHI has brought the debate to a completely new level. That is, in the RHI, a new body is created by tricking the mind into thinking that it can perceive stimuli arising from an artificial prosthesis. But what happens to the real body once this illusion has been established? Can a body continue to exist without a mind to control it? Answering these questions has become even more important following the advent of VR technologies. In fact, just as we saw in the last paragraph, scientific progress has now made the possibility of creating virtual bodies or avatars possible. Therefore, it is not surprising to observe that over the last few years, researchers have started to investigate the physical consequences of owning artificial bodies. In particular, they have concentrated their efforts on studying the physiological effects related to manipulations or alterations of body ownership (e.g., Moseley et al., 2008a, 2012a).

Earlier in this chapter we saw that whenever we start to perceive that our body is placed in a position that is different from that where it really is (or when participants cannot correctly locate it), a sense of body disownership may develop (Guterstam & Ehrsson, 2012; see also Newport &

¹ Note that even if René Descartes (1637/1980) supported the distinction between these two aspects back in the seventeenth century, he also highlighted the fact that the link between them is very strong, as this quote might suggest: "Nature also teaches me by the sensations of pain, hunger, thirst, etc. that I am not only lodged in my body as a pilot in a vessel, but that I am very closely united to it, and so to speak so intermingled with it that I seem to compose with it one whole . . ."



Fig. 8.7 Portrait of René Descartes (1596–1650), French philosopher and writer.

Gilpin, 2011). Moreover, a large body of research on different clinical conditions such as schizophrenia, bulimia, anorexia post-stroke neglect, has revealed that body disownership can be associated with a disruption of homeostatic functions, such as thermoregulatory control (see Moseley et al., 2008a). Following on from these considerations, it becomes clear that the RHI might play an important role in the study of the relationship between mind and body. That is, whenever our mind starts to perceive that the body does not belong to it anymore, are there any consequence for the physiological functioning of the body itself? Does the mind keep maintaining homeostatic control, not to mention more general control, over vital bodily functions in a body (or body part) that is no longer perceived as belonging to itself?

Moseley, Olthof, Venema, Don, Wijers, Gallace, and Spence (2008a) were the first to investigate the relationship between body and mind by using the RHI and its effect on homeostatic control. In particular, over a series of experiments, they induced the RHI on neurologically normal participants (by using asynchronous visuotactile stimulation of the real and rubber hand) and measured the temperature of their hands. Surprisingly, they found a small but significant drop in the temperature of the “replaced” hand (see also Hohwy & Paton, 2010; Thakkar, Nichols, McIntosh, & Park, 2011, for subsequent replications of this effect). That is, whenever the participants started to perceive that the rubber hand was part of their own body there was a disruption of thermoregulatory control in the part of the body placed on the same side of the rubber hand. What is more, this drop in limb temperature was positively correlated with the strength of the illusion, such as that in those participants who felt stronger sensations about the ownership of the rubber hand, the drop approached 2° C (on average the drop was $0.8 \pm 0.2^{\circ}\text{C}$).

Inducing the RHI not only affected thermoregulatory control, other important physiological functions were also modulated. In particular, inducing the illusion has been shown to increase histamine reactivity in the hand placed on the same side of the rubber hand (Barnsley, McAuley, Mohan, Dey, Thomas, & Moseley, 2011; see also Moseley, Parsons, & Spence, 2008b; Mancini, Longo, Kammers, & Haggard, 2011, for the report that altered perception of body size can modulate pain perception). This result clearly suggests that whenever we start to feel that we own an artificial body part and that our real body part has been replaced by it, our immune system reacts

as a consequence. Here it is important to highlight that in order to work efficiently the primary role of the immune system must be to “discriminate self from non-self”

Importantly, in a number of clinical conditions involving a disturbance in a person’s sense of body ownership, such as in schizophrenia (e.g., Priebe, 2001; Thakkar, Nichols, McIntosh, & Park, 2011), neuropathic pain (e.g., Moseley, 2005), stroke (e.g., Halligan, Marshall, & Wade, 1993), anorexia (e.g., Bruch, 1962), and bulimia nervosa (e.g., Slade, 1985), thermoregulatory dysfunctions have also been reported. Finally, note here that the relationship between body ownership and thermoregulatory control does not only occur in one direction. That is, changes in body temperature can also be effective in modifying processes related to body ownership. For example, Kammers and colleagues (2011) have now demonstrated that cooling down their participants’ real hands increased the strength of the RHI, while warming the hands decreased its strength. The results of this experiment somehow remind one of those situations in which people experience that their hands feel like a “piece of ice” or a “stick” at very cold temperatures.

The evidence reported here clearly suggests that whenever our mind tells us that a given body part does not belong to us anymore, physiological reactions relating to that body part might be disrupted. One might then wonder about what the physiological consequences of owning a virtual avatar within a virtual environment are likely to be? In this case, will the activation of automatic lower-level control mechanisms in our brain override the dysfunctions provoked by the alteration at the level of higher-order cortical areas responsible for maintaining our sense of body ownership? For the safeguard of human operators working (or acting) within a VR environment, research in the years to come will certainly need to provide answers to these important questions. Note, however, that research on these topics may also show another side of the coin. One might, in fact, legitimately ask whether, from an ethical point of view, it is correct to artificially distort a person’s body image in a laboratory setting, especially if there turn out to be long-term consequences of these distortions. And finally, but no less importantly, by creating artificial or virtual prostheses that are integrated into one’s person body representation we are offering people the possibility to develop “super-human” skills or abilities, are there any potentially dangerous implications of doing so? At the moment even these basic questions have no answers.

8.6 Neural bases of body ownership

8.6.1 Body ownership in the scanner

A number of studies conducted over the course of the last decade have started to investigate the neural correlates of body ownership by means of brain imaging techniques. In particular, Ehrsson, Spence, and Passingham (2004) used fMRI to demonstrate that just before the RHI illusion was elicited an increase in the activity of bilateral intraparietal cortex, bilateral dorsal premotor cortex, and supplementary motor area, as well as the left cerebellum, left putamen, and left ventral thalamus was observed. Given that these areas are known to be involved in the processing of proprioceptive signals, it is unsurprising to find that they should be involved in establishing this illusion. Ehrsson and his colleagues also found that the strength of the illusion, as rated by the participants, was correlated with BOLD signal changes in the bilateral premotor cortex (see also Bekrater-Bodmann, Foell, Diers, & Flor, 2012, for the involvement of the ventral premotor cortex in the RHI). This result clearly suggests that this particular brain area is important in terms of establishing the feeling of ownership over a particular body part. Given that self-attribution of body parts depends on a match between the look and feel of such body part, it isn’t so surprising to find that body ownership is related to a brain area that responds to

both visual and tactile information (e.g., Graziano, Yap & Gross, 1994; Lloyd, Shore, Spence, & Calvert, 2003; see also Blanke, 2012, for a discussion of the multisensory mechanisms underlying bodily awareness).

Tsakiris, Hesse, Boy, Haggard, and Fink (2007) also investigated the neural signature of body ownership using positron emission tomography (PET). They reported that the sense of body ownership elicited by the RHI was related to neural activity in the right posterior insula and the right frontal operculum. Such results support the view that activity in neural networks within the frontal lobe, especially in the right hemisphere of the brain, correlates with the feeling of ownership over an artificial limb and its maintenance.

In section 8.2, we mentioned that Schaefer et al. (2008) used an artificial hand and arm that appeared visually to be connected to the participant's own body to give their participants the impression that they had a supernumerary third arm (situated in a central location between the real hands; see also Guterstam, Petkova, & Ehrsson, 2011). In addition to the behavioral data obtained by means of a questionnaire response (showing that six out of eight participants tested felt as if they had three arms), the authors of this study also collected neuroimaging data by means of MEG. They found that the activation of SI was modulated by the perceived presence of the supernumerary limb (i.e., the cortical representation of the thumb shifted to a more medial and superior position). What is more, this modulation was positively correlated to the strength of the feeling that the third arm actually belonged to the participants. That is, changes to our sense of ownership toward a given body part (even when its presence is inconsistent with the conventional human anatomy) seems not only related to the activity of higher-order cortices but also results in modifications at the level of the activity of sensory specific areas.

8.6.2 The body matrix

In order to integrate the discoveries arising from the study of body ownership, and, in particular, those related to the consequences of body ownership over physiological variables such as thermoregulatory control, a neurocognitive model, “the body matrix,” has been proposed recently (Moseley et al., 2012a; see also Gallace, Soravia, Cattaneo, Moseley, & Vallar, submitted; see Figure 8.8). The body matrix can be seen as a complex network of brain areas sustaining a multisensory representation of peripersonal space, and, in particular, the space directly around the body. This representation is likely to receive inputs from areas of the brain involved in the coding of visual, tactile, and proprioceptive information. In fact, within this network, a key role is thought to be played by higher-order (multisensory) areas, such as the posterior parietal cortex (PPC). The PPC is responsible for integrating different (somatotopic and spatial) frames of reference used for the localization of external stimuli and of the position of the body in space, as well as for sustaining a coherent multisensory representation of the body (e.g., Ehrsson et al., 2005a).

An important difference between the body matrix and other representations of peripersonal space (see Chapter 4) is that the body matrix is aligned with a body-centered rather than with hand-centered frame of reference. That is, stimuli arising from the left side of external space and within the body matrix are always mapped as “left,” regardless of the fact that they arise from the left hand, or from the right hand when placed in the left space (and regardless of their sensory modality). Note, however, that under those conditions in which the hands are crossed over the body midline, the strength of the connections from somatotopically organized areas might change (Gallace et al., 2011c). The fact that this representation is rather coarse and extends beyond the boundaries of the body surface itself allows external objects, such as rubber hands (or tools), to

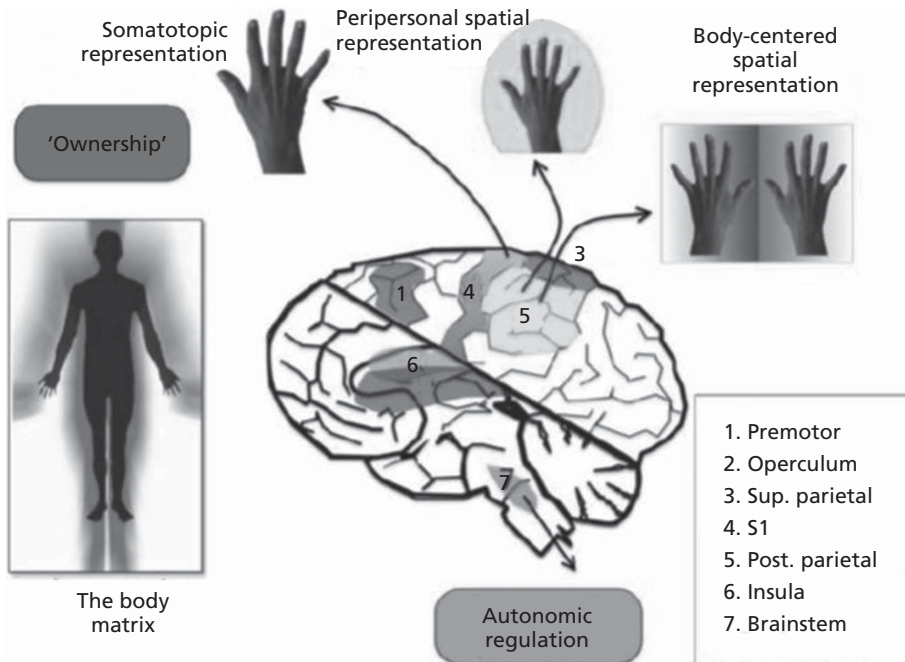


Fig. 8.8 Representation of the brain areas involved in sustaining the cortical “body matrix”.

Data from *Neuroscience & Biobehavioral Reviews*, 36 (1), G. Lorimer Moseley, Alberto Gallace, and Charles Spence, *Bodily illusions in health and disease: Physiological and clinical perspectives and the concept of a cortical ‘body matrix’*, pp. 34–46, 2012.

be perceived as part of our body. The limitations of the body matrix, in terms of its capability to integrate external objects has yet to be fully tested.

It has been argued that the main purpose of the body matrix is to maintain the integrity of the body at both the homeostatic (i.e., thermoregulatory) and psychological levels (Moseley et al., 2012a). This neural network might therefore supervise the distribution of cognitive and physiological resources necessary to protect the body surface and the space around it. Control over physiological functions is likely achieved by the connections that exist between the PPC and the insula. In fact, there are a number of inhibitory connections between the insula and autonomic brain stem structures (see Fechir et al., 2010). Importantly, the insular cortex plays an important role in several illusions of body ownership, such as the RHI (Tsakiris et al., 2006, 2007). In particular, this part of the brain increases its activation when participants attribute an observed action to themselves. Even more importantly, the level of activation of the right posterior insula is correlated with the strength of the RHI (measured by means of the proprioceptive drift; see Tsakiris et al., 2007).

The main rationale underlying the body matrix model is that evolution has prepared brains to adapt to even major changes in body anatomy. In fact, as far as the evolution of ontogeny (the development of an organism) is concerned, our body is affected by major modifications from birth to death (e.g., Prader, Largo, Molinari, & Issler, 1989). For example, at birth our head is 25% of our entire body length, while in adulthood this proportion drops to just 12%. Note also that different body parts grow at different speeds during our development and that certain body parts can be radically re-sized as a consequence of injury. The brain must cope with these changes. From a phylogenetic point of view (regarding the sequence of events involved in the development

of groups of organisms), it is much less expensive (in terms of evolutionary efficiency) to design a single neural network that is adaptable to multiple body structures than to design a separate network for each of these structures. This is even more plausible if one considers that most animals have similar inner body architectures: a central spine, four limbs, a head, two eyes, and so on. In conclusion, the body matrix should be considered a useful model that is capable of merging the evidence related to the brain's ability to integrate external objects in our body representations and that related to the physiological consequences of body ownership manipulations (as well as other data comprising the effect of spatial manipulations on pain and somatosensory processing in neurologically normal participants and clinical populations that are not discussed here; see Moseley et al., 2012a, for a review).

8.7 Conclusions

In this chapter, we have seen that somatosensory sensations and multisensory integration play a very important role in supporting coherent representations of our body in the brain. Such representations might be sustained by our brain in order to adapt to changes occurring to our anatomy (such as during development or in the cases of amputations), but also to integrate artificial or virtual prosthesis into its circuits (thus going beyond natural limits on anatomy). With the RHI, it has been demonstrated that our sense of ownership can easily extend toward external body parts, objects, or even entire bodies, no matter if they look like our own body or not. The experiments reported in this chapter have shown that by means of visuotactile integration we can perceive our body as being of different size, shape, and even gender than it really is, and can still feel it as “our own.” Taken together, this evidence regarding the plasticity of our body representations, opens up intriguing (though ethically controversial) possibilities, such as the development of virtual and real prostheses that are perfectly integrated into our brain networks and that are able to augment our skills and motor functions.

The research reviewed in this chapter has also highlighted how playing with the boundary between mind and body, laying in what we defined as the “body matrix,” has important consequences on the physiological point of view. These consequences derive from the fact that our brain defends, protects, and physiologically regulates what it perceives to be part of itself, but not the rest! The extent of these consequences, as well as the pros and cons of exploiting them, are matters that will likely keep psychologists, philosophers, and neuroscientists, busy in the years to come. Certainly, at the end of this chapter, the thought of “feeling touch without a body” (with all of its implications for the development of VR), no longer seems to be merely an absurd possibility.

Section C

Touch in the real world 1: Overcoming the limitations in tactile information processing

Chapter 9

Technologies of touch

So let's not use a stylus. We're going to use the best pointing device in the world. We're going to use a pointing device that we're all born with—born with ten of them. We're going to use our fingers. We're going to touch this with our fingers. And we have invented a new technology called multi-touch, which is phenomenal. It works like magic.

(Steve Jobs' original iPhone keynote address, Macworld Conference, San Francisco, 2007)

9.1 Introduction

Advances in technology have always played a crucial role in human evolution, everything from the invention of the wheel through to the latest microprocessor (e.g., Taylor, 2010). Not only do technologies change (sometimes drastically) the way in which we live, but they can somehow also become a part of ourselves, changing the way in which our brains deal with the external world. This would seem particularly true for haptic and tactile technologies. One everyday example of how haptic technology affects the way in which our brains interpret external stimuli is something that many readers have likely experienced when using a mobile phone. Most of these devices (if not all of them nowadays) are equipped with vibrators capable of informing their owner about the arrival of an incoming call or text message in a more or less silent manner. If you own one of these devices, it is quite usual (at least it is for one of the authors of this book and for the 70% of a sample population of mobile phone users in a recent survey on this topic; see Rothberg, Arora, Hermann, Kleppel, St Marie, & Visintainer, 2010) to feel a vibration in one's pocket, reach for one's phone, only to realize that no call or text has arrived. This peculiar phenomenon has now become an object of serious scientific investigation. It even has a name: "Phantom vibration syndrome."

Researchers working on this topic believe that it occurs because of a misinterpretation by our brain of incoming signals (e.g., Rothberg et al., 2010; see also Baillie, 2011). That is, our body gives rise to a very large number of somatosensory sensations at each and every moment, the majority of these sensations are filtered out, and thus do not enter into awareness (see Chapter 4; see also Brown, Skehan, Chapman, Perry, McKenzie, Lloyd, Babbs, Paine, & Poliakoff, 2012). Those sensations that are relevant to us normally pass this filter and reach the level of consciousness and/or affect our behavior. Most likely, random vibrations were once considered as irrelevant stimuli by our brains (e.g., they were considered as arising from the activity of muscle contractions or by the friction generated from the contact between our body and any clothing that we happen to be wearing), but with the advent of vibrating mobile phones they suddenly become relevant. Thus, our

brains have had to change the way in which they deal with these kinds of stimuli (from filtering to alerting) as a function of the advent of a new technology.

Another important aspect to be considered here is that haptic and tactile devices, by allowing us to create new forms of manual interaction with the outside world, are likely integrated into our representation of the body and of its movement (see Chapter 8, for a review of changes to our body representation; see also van Elk & Blanke, 2011, for the report that the mere observation of manipulable objects, such as mobile phones, can facilitate crossmodal integration in the peripersonal space around the observer). Movie makers would seem to have exploited this concept extensively, envisioning futuristic worlds in which people would be able to control virtual (see the movies *The Matrix*, 1999, or *Avatar*, 2009), or robotic (see the movie *Surrogates*, 2009) counterparts of their own selves by means of some sort of brain interface. Indeed, the history of literary fiction is rich with unfulfilled “prophecies,” as well as with a few examples of successful predictions (see, for example, *20,000 Leagues Under the Sea* by Jules Verne, 1870, where the invention of submarines and the use of scuba tanks for marine exploration was anticipated by nearly three decades; and Upton Sinclair, predicted the arrival of the clothes washing machine in 1906).¹ So, what should we expect from haptic technologies in the future? Will we really live our lives by means of a “surrogate” of our own body, one that is able to convey tactile as well as multisensory information to our real body or directly to our brain?

Making predictions in this fast-moving area is by no means an easy matter, but one can certainly observe the state of the art in terms of haptic and tactile technologies at the moment, and use such information in order to define some of the most likely trends for future developments in the field (see Chapter 13). What is certain, though, is that many of these technologies are here to stay. This is how Steve Jobs (co-founder, chairman, and chief executive officer of Apple, before he died in 2011) once put it: “These technologies can make life easier, can let us touch people we might not otherwise. You may have a child with a birth defect and be able to get in touch with other parents and support groups, get medical information, the latest experimental drugs. These things can profoundly influence life. I’m not downplaying that” (<http://www.wired.com/wired/archive/4.02/jobs_pr.html> downloaded on October 10, 2012).

The first section of this chapter deals with the increasing, and increasingly successful, use of robotic technologies in order to perform operations in those patients requiring a variety of different surgical procedures. Next, we will review those studies that have addressed the use of touch in VR, to increase the sense of presence of the user within the simulated environment, but also to provide tactile and haptic information to designers and engineers performing virtual 3D modeling. The concept of “augmented reality” (AR) in touch, used to compensate for the sensory decline that commonly affects the elderly, as well as to provide more information than naturally available (e.g., for providing sensations that our receptors are generally not capable of perceiving), to healthy and sensorially impaired individuals will also be addressed. Next, the important role of the most social aspects of tactile sensations, comprising those related to our sexual life, both within virtual worlds and through mediated interactions will be discussed. This chapter will also deal with the interaction between our body and a large number of external devices (everything from mobile phones to touch screens) that are now a ubiquitous presence in many of our worlds.

¹ As John W. Campbell, a successful science editor once wrote: “science fiction exists in the gap between the laboratory and the marketplace” (see <<http://www.nytimes.com/roomfordebate/2011/09/29/science-fiction-so-crazy-it-might-come-true-14/science-fiction-imagines-so-inventors-can-invent>> downloaded on October 17, 2012).

The final section of this chapter is dedicated to tactile sensory substitution systems, devices that allow for the translation of the stimulation occurring in one sensory modality (e.g., vision or audition) into tactile sensations. In particular, the important role that many of these technologies play, especially for those individuals suffering from a sensory impairment, and for the rest of the population, will be discussed.

9.2 Touch in the operating theater: Robotic and virtual surgery

Robotics has certainly come a long way from merely being a part of movie and book fiction to actually being used efficiently in our life. In particular, in the 1980s, robots were specifically designed in order to perform certain surgical procedures under the guidance of expert surgeons. So, for example, in 1980, the robot PUMA 560 was first used to place a biopsy needle into a patient's brain using neuroimaging techniques for guidance. A few years later, the robot "PROBOT" (specifically designed to allow a surgeon to specify a volume within the prostate that needs to be cut, and then to automatically section it) was adopted at St Thomas' Hospital, London, for patients undergoing prostate surgery. In 1998, Dr. Friedrich-Wilhelm Mohr together with Professor Alain Carpentier, used the "da Vinci Surgical System" to perform the first robotically assisted mitral valve repair and coronary bypass surgery in Paris. Since then, these devices have started to become an increasingly common feature of operating theaters, accompanying the activity of surgeons around the world (see Murray, 2012). The surgeon uses a telemanipulator (a remote interface) that allows him/her to perform those movements that are required during specific surgical procedures. Robotic arms, located in the same, or sometimes in a different room, reproduce those movements by means of effectors (surgical instruments) so that they can operate on the patient. The instruments attached to the robotic arms are able to perform certain actions (such as incisions) with a degree of precision and smoothness of motion that is much better than could be achieved directly by a human hand.

There are certainly many advantages to using these technologies, including increased precision, miniaturization, smaller incisions, decreased blood loss, less pain, and quicker healing times for the patients (e.g., Overstreet & Sims, 2006; Park, Kim, Jeong, Jeon, Lee, Choi, & Seo, 2013). Note also that robotic operating systems, such as the da Vinci, are capable of filtering out any tremors in the surgeon's hand movements, so that they are not duplicated robotically. One final beneficial aspect of robotic surgery is related to the possibility of operating on those patients who happen to be miles away from the surgeon (this is known as remote surgery; see Murray, 2012).

One of the major problems in the use of devices for telesurgery is related to the perceived, as well as the physical, delay between the action currently being performed by the surgeon and that subsequently executed by the robot. For example, when a doctor operates on a patient in a remote location, even a few milliseconds of delay between the actions performed by the doctor using the interface and the real-time output on the patient, can certainly be severely detrimental to the outcome of the operation. Indeed, in this case, delay can mean the difference between life and death (see Marescaux et al., 2001; Marescaux, Leroy, Rubino, Smith, Vix, Simone, & Mutter, 2002).

Another downside to robotic-assisted surgery is its cost. However, as far as this point is concerned, it is important to note that even if the cost of the robot and of the disposable materials required to operate is very high, the cost related to the human factors involved in the operation might well be even higher. In fact, as the following quote can be taken to suggest, surgeons need to be given extensive training in order to use these devices effectively, and it has been estimated that they must operate on as many as 18–20 patients before they are fully adapted to this way of operating (e.g., Gross, 2012; Rassweiler, Binder, & Frede, 2001; Meyer, Gharagozloo, Tempesta,

Margolis, Strother, & Christenson, 2012). That is, the way in which our brains interact with such haptic interfaces, and integrate their controlling procedures in its neural circuits, seems to constitute an important point in terms of their successful use.

As Professor Peter G. Schulam, M.D., Ph.D., David Geffen School of Medicine, UCLA put it: “If you have to choose between someone who hasn’t performed many robotic surgeries and a person who has performed many open procedures—take the open procedure” (see <<http://www.science-daily.com/releases/2005/08/050829073446.htm>> downloaded on September 24, 2012).

It is also important to consider here that human anatomy and sensory systems are somewhat different from those of robots. For example, robotic hands can open, close, flex, and rotate by 170 degrees, something that no human hand can do. In other cases, the robot hand may be restricted by more limited degrees of freedom in the movements that they can accomplish (e.g., when compared to the human hand). The difference becomes even more important when it comes to touch, a sense that provides surgeons with essential feedback in normal open surgery, for locating arteries and tumors hidden in tissue or performing certain sutures. For example, suturing a coronary arterial anastomosis (the surgical connection of severed arteries to form a continuous channel) with a fine suture made of polypropylene is, to say the very least, a rather complex task. The surgeon has to use his/her sense of touch to puncture tissue with a needle, pull the suture through, and then tie the knots (see Okamura, 2004). Despite the undoubted importance of tactile feedback to the success of many conventional operational procedures, most robotic surgery devices currently provide no tactile feedback at all (e.g., Okamura, 2004). As a consequence, many surgeons find the lack of direct contact with the instruments, or for that matter with the patient’s body, rather disconcerting (see also Glickson, 2012, for an increase in the last years in ergonomic-related stress within the operating room). This is how Dr. Michael Esposito, a surgeon in the New Jersey Center for Prostate Cancer & Urology, who has performed about 425 robot-assisted surgeries, describes the situation: “[when using robotic surgery] your vision becomes a surrogate for tactile feedback.” That is, vision needs to substitute (see section 9.6) for the missing sense of touch. This is certainly something that needs a lot of cognitive resources in order to be performed successfully. One might somehow link this condition with that of those patients suffering from a complete lack of tactile sensation, and who require enormous amounts of attentional resources (e.g., concentration) to perform even simple movements under visual control (e.g., Cole, 1991; see Chapter 4).

Another important aspect to be considered here is that in robotic-assisted surgery or tele-surgery, visual information coming from the to-be-operated patient is often magnified (e.g., Aurora & Talamini, 2004; see also Taleb, Nectoux, & Liverneaux, 2008). We have already seen in many of the earlier chapters that visual information can affect the way in which tactile information is processed. In particular, watching a given body part when it has been magnified can result in increased tactile sensitivity in that body part (e.g., Haggard, Taylor-Clarke, & Kennett, 2003; Kennett, Taylor-Clarke, & Haggard, 2001; see also Heller, 1985). One might wonder, then, whether a similar phenomenon would also occur while operating when using robotic-assisted surgery. Note, however, that those surgeons operating with the aid of such devices typically do not see their own body, but only the robotic instruments. As a consequence, any increase of tactile sensitivity that might occur as a result of viewing a magnified visual image (something that might occur in conventional microsurgery) might be lost under these operating conditions (leading to the question of how to reinstate it).

Another question related to visual magnification concerns the kinds of information that a haptic interface should ideally provide in a robotic surgery system. That is, magnification by high resolution (and eventually 3D) camera, allows humans to perform on a scale that we are certainly not used to experiencing in our everyday tactile interactions with the world. Contact with

micro-objects is unlikely to result in any tactile sensation at all. So what kind of tactile feedback should be reproduced within such a system? What kinds of sensations can one expect to be generated by cutting a surface that we have never ever experienced before? Answers to these questions are certainly relevant if one's aim is to increase the intuitiveness of robotic surgery by means of adding tactile feedback to these systems.

A final issue to be considered here regarding haptic interfaces in robotic surgery relates to the spatial alignment between the visual and tactile signals during the operation itself. That is, when performing standard open surgery, the surgeon stands close to the operating table where the patient's body is lying. He/she can see the surgical instruments directly under his hands as well as the to-be-operated-on organ(s). That is, tactile as well as visual (and eventually auditory or olfactory signals) all come from a well-delimited portion of the surgeon's peripersonal space (see Chapter 4). In contrast, in robotic-assisted surgery, the surgeon often uses interfaces that are not located in the same position as the monitor where the actual operation is shown (see Simorov, Otte, Kopietz, & Oleynikov, 2012, for a review of the critical aspects of robotic surgery). Given that a large body of literature that has been published over the last few decades has consistently shown that alignment between different sensory signals improves people's performance in a number of tasks (e.g., Spence & Driver, 2004), one might wonder whether this aspect might contribute to overloading the surgeon's cognitive resources when using these kinds of devices. That is, the surgeon's brain, needs to: (1) constantly monitor the very large amount of information coming from different senses and from the motion of his/her body; (2) be cognitively engaged in understanding any possible complications that might arise from the operation; (3) realign different spatial coordinate systems in order to perform the correct actions on the patient's body. That's a lot of complex actions to be executed pretty much simultaneously by the surgeon's neural system.

Haptic interfaces are not only used to perform actual operations on patients mediated by a robotic system, they have also been adopted in order to train surgeons on new surgical procedures (e.g., see Gallagher, Ritter, Champion, Higgins, Fried, Moses, Smith, & Satava, 2005). That is, what was once mainly accomplished by means of observing other surgeons performing, or by operating on corpses, can now be achieved by means of virtual visuohaptic simulation (e.g., Coles, John, Sofia, Gould, & Caldwell, 2011; Ho, Alsaffar, Doyle, Ladak, & Agrawal, 2012; Willaert, Aggarwal, Van Herzele, Cheshire, & Vermassen, 2012; see also Baillie, Crossan, Brewster, May, & Mellor, 2010, for the use of haptic technologies in the training of veterinary students). The results of these kinds of surgery are very useful for operations such as laparoscopic surgery (a technique where operations are performed through small incisions, distinct from "laparotomy" where larger incisions are needed) where the surgeon cannot physically see the operation being performed (e.g., Clarke, 1972). By means of virtual surgery, rare pathological cases, and possible complications that might occur during surgery can be simulated, thus preparing the surgeon to face a whole host of potential scenarios that he/she might be expected to come across during the course of actual surgery. Moreover, expert surgeons can also benefit from this technology. In fact, operations in a given patient can be simulated well in advance of the actual time of execution of the surgery. This can be achieved by reconstructing virtual counterparts of the patient's body (or organs) by means of CT scans (e.g., Reitingier, Bornik, Beichel, & Schmalstieg, 2006) and operating on such simulations. Similarly, augmented reality (be it visual, haptic, or multisensory) might be successfully used by surgeons in order to provide additional feedback regarding the procedures accomplished and the vital physiological parameters of the patient (e.g., Yamamoto, Abolhassani, Jung, Okamura, & Judkins, 2012).

Despite the clear advantages provided by virtual surgical interfaces, this technology also suffers from similar, if not even more severe, limitations than those seen for robotic surgery systems.

That is, the paucity of tactile information provided within the virtual environment, and the need to understand what and how to simulate it, would also seem to adversely affect this domain.

Touch is not only of relevance, however, to the field of robotic surgery. Another important application of this sense within the context of the operating theater is related to the possibility that it offers to the surgeon of providing additional information regarding certain vital parameters from the patient undergoing the operation. In fact, a number of visual and auditory signals, informing the surgeon and the operating team about such things as the patient's heart rate, blood oxygenation level, their blood pressure, and their lung volume, all need to be carefully monitored during the course of the operation.

Ferris and Sarter (2011) recently investigated whether the addition of informative tactile signals would improve the performance of anesthesiologists involved in the surgical procedure. They conducted a study in which they presented lung volume information to the anesthesiologist's back while presenting blood pressure information to his/her arm by means of vibrotactile displays. Using such a device, the authors were also able to incorporate the severity of a patient's condition into the salience of the signals delivered (i.e., by changing the intensity or frequency of vibrations as a function of the values of a given parameter; e.g., increases or decreases of blood pressure). The results revealed that the addition of tactile information elicited superior performance as compared to the standard audiotactile interfaces that are generally adopted in operating theatres today. It is, however, also important to bear in mind here that the continuous presence of the tactile display caused discomfort and annoyance to the anesthesiologists. As a consequence, despite the better performance obtained with the addition of the tactile interface, the doctors still preferred the standard audiovisual, or multisensory, displays where the information was not provided continuously to their body. That is, haptic displays certainly offer several advantages over traditional means of displaying the information in the operating theatre. However, in order for these devices to reach their full potential, the best temporal patterns of the signal to be communicated (continuous vs. temporary), and the most effective locations to be stimulated across the body surface, need to be investigated more carefully.

9.3 Virtual touch: Touch in VR, haptic rendering

If the reader has ever experienced visual or audiovisual VR, he/she will no doubt be familiar with the feelings generated by such devices. After a first reaction of surprise and amusement in front of a rather accurate reproduction of reality (at least in high definition and highly dynamic simulations), a kind of frustration soon replaces the initial positive emotions that one experienced. That is, the breeze that moves the leaves of the trees in a beautiful landscape does not generate any sensation on your hair or face, and the fire burning in a chemical plant is not at all hot, nor even warm (how, then, can it be anything like close to dangerous?), and if you extend your hand (if you can actually see your own hand or body in the simulation) trying to reach for the handle of a washing machine or fridge, say, you simply pass through the object, like a sort of modern-day technology-generated ghost. Is that really all that future technology has to offer? That is, without tactile sensation, VR simply does not seem to deliver the degree of "presence" that would be required to make a simulation "believable" by the user (e.g., Barfield & Weghorst, 1993).

Those involved in the development of VR systems are now realizing that enhancing the visual parameters of a simulation (with all of the high costs that are associated with it), such as increasing the screen resolution, dimensions, refresh rate, 3D rendering, or dynamic range tends to result, nowadays, in only a relatively modest enhancement in the user's sense of presence. And

sometimes, it doesn't even result in any noticeable improvement in people's performance within a given environment (see Barfield & Hendrix, 1995; Dinh, Walker, Hodges, Song, & Kobayashi, 1999; Hendrix & Barfield, 1996; Wickens, Olmos, Chudy, & Davenport 1997). As a consequence, developers of VR systems need to look elsewhere in order to enhance the sense of presence that they can achieve through their VR simulations. And what better place to look than the sense of touch? In fact, certain researchers have even gone so far as to argue that simulating believable tactile and haptic sensations might represent "the Holy Grail" of VR. This is likely due to the fact that, just as seen in Chapter 1, the sense of touch is the one that contributes most to making things "real" to us, the one that cannot be fooled, and perhaps even the most arousing of our senses.

Note here that most of the VR systems that have been developed to date, have primarily tried to replicate tactile sensations at one of the body surface's most sensitive (and accessible) locations, namely the hands and fingertips (see Demain, Metcalf, Zheng, & Cunningham, 2013; Iwata, 2008, for a reviews of the haptic stimulation devices that are currently available). Bear in mind, though, that certain of these devices do not actually stimulate the fingers. Instead, they work rather like a kind of airplane pilot's stick (just with more degrees of freedom in terms of the movements that you can perform with them), held in your hands. If you are not really experienced with controlling such a device, even a simple operation, such as trying to open a drawer, may result in a great deal of frustration. That is, devices like these are not really what we would define as the "simulation of touch." Rather, these approaches merely provide tools that allow for indirect tactile interactions with a simulated environment. In that case, there is not a "me" and "the object"; There is simply just the user and an instrument that allows that user to gather certain information from the object, just as a pinch or a probe (that the user can use to grab or poke the object). The presence, or most importantly, the "perception of the presence," of a third part (the tool) in the interaction makes, in our opinion, the simulation (and hence the sense of presence generated by it) much less convincing.

As an alternative to virtual tools, there are those devices that allow for the simulation of sensations coming from the hands and their movements: The haptic gloves (e.g., Culjat, Son, Fan, Wottawa, Bisley, Grundfest, & Dutson, 2010). There are currently many versions of these devices available in the marketplace coming in at a very wide range of price points. Some of them only allow for the reproduction of accurate hand movements within a visual environment, others also provide information (by means of a vibrating device attached to the fingertips of the glove) concerning the contact between the user's hand and the virtual object. Others, meanwhile, also provide proprioceptive signals regarding any interaction with the object. In the latter case, information regarding the solidity, or inner structure, of an object is provided by simulating the mechanical forces involved in manipulating it (i.e., by means of force feedback). Force feedback devices are certainly more effective in terms of simulating an interaction between the hand and an object. However, at the same time, they also tend to be more complex from an engineering perspective, and generally they are physically bigger (due to the presence of the servo systems and actuators; see Nelson, Flood, Bryant, Huang, Pasquina, & Roberts, 2006, for the report that many individuals who have had a limb amputated choose to avoid the hassle of a prosthesis for this very reason) than simple vibrotactile stimulators. The use of the latter devices is generally limited to the hand given that they become cumbersome when applied to larger parts of the body (such as, for example, the arms or the trunk; e.g., Gopura & Kiguchi, 2009; Lo & Xie, 2012). Here, it is important to note that, at the moment, none of these devices is able to reproduce a real and complete tactile/haptic interaction with an object (cf. Bordegoni, 2011). In fact, whenever we grasp an external object, we get information regarding the structure of the object (by means of

proprioceptive signals) but we also receive information regarding its surface (if it is wet, soft, rough, etc.). Different receptors in the skin (or their combination) contribute to the transduction of all of these different aspects of a tactile stimulus (see Chapter 2). A haptic glove can simulate the contact with the object, its shape, and even its solidity, but not (at least not at the present time) all of the characteristics of its surface (that can instead be reproduced by other kinds of device) or its weight. That is, the multisensory nature of touch is still far from being realistic when using such virtual devices.

Technologies such as haptic gloves are now used in a range of fields, and especially where the visual reproduction of accurate hand movements is required within a VR simulation. For example, many studies have now started to investigate the use of haptic gloves for the rehabilitation of patients who may have lost their ability to move and/or feel sensations in their arms, as a consequence of stroke (e.g., Boos, Qiu, Fluett, & Adamovich, 2011; Confalonieri, Guandalini, Da Lio, & De Cecco, 2012; Kim, Chun, Song, & Young, 2011; Merians, Tunik, & Adamovich, 2009; Merians, Tunik, Fluett, Qiu, & Adamovich, 2009; Placidi, 2007; see also Ku, Mraz, Baker, Zakzanis, Lee, Kim, Kim, & Graham, 2003). This application often allows a transition of the rehabilitation process from traditional hospitals or clinics to the home environment (with a resulting decrease in the costs for the healthcare systems responsible) as well as a more precise monitoring of the patient's performance and progress.

An area in which haptic gloves are certainly well suited is that of computer and console gaming. In fact, adding tactile content to videogames is likely to allow for more realistic and entertaining interactions and thus more enjoyment for the end user. Not surprisingly, then, a number of videogame companies have tried in recent years to develop (and sell) haptic gloves for gaming purposes. It now seems as though ages have passed since Nintendo developed the "Power Glove" (in 1984). This particular device was designed to react to the movement of the hand and fingers in order to control the action onscreen. Indeed, it can be considered as one of the first examples of a haptic glove used as a controller for videogames. Since the emergence of the Power Glove, many other devices have appeared on the gaming market. All of them unified by pretty much the same fate, they all failed to become a central part of gamer's habits. In most cases, these systems required specially designed games (so, for example, in the case of the Power Glove, only two videogames were ever released for use with it) while, in other cases, they simply proved to be too expensive for home use; as a consequence, they never really caught on (amongst users). By contrast, other devices such as the Wii (that exploit movement and proprioception in order to control action videogame by means of a tangible stick-like interface), again developed by Nintendo, have had a much more success in the marketplace.

One might wonder what actually makes one haptic device more successful than another when it comes to videogames. There are many important aspects to be considered here. One of them is certainly related to the use of the device itself. Systems such as the Wii are tools used to control a videogame; as such they need to be intuitive. Using a Wii resembles the use of a tennis racket, or a golf club, something that does not really require haptic manipulation (i.e., the gathering of information regarding the shape and characteristics of the object by moving our hand across it). That is, the interface is used to control the videogame and the sensation of holding an object in the hand contributes to the game's sense of realism (note that, as an Internet search can confirm, a number of cases are reported of users throwing the controller against the screen while playing certain games, such as bowling, using the Wii; in fact, Nintendo sells the Wii with an attachable wrist strap that can be used to prevent the player from dropping or throwing it unintentionally). In the case of the Power Glove, hand movements were used as a means of controlling a game, something that doesn't resemble a natural interaction with the world around us. That is, it seems

as though haptic gloves need to convey information in a way that is intuitive and well known to the user in order to be effective as a gaming interface. Exploring a completely dark cave with your bare hands while playing *Tomb Raider* from a first-person perspective is certainly something that might well be expected to boost the excitement of the game, while opening and closing your hand in order to use a first-aid spray in *Resident Evil*, say, probably is not (because of the lack of similarity with the actual movements and sensations elicited by the equivalent action in the real world). That is, failing to understand what touch and proprioception are used for, and how our brains interpret those signals in the real world, often results in the development of unsuccessful haptic interfaces for VR.

As seen so far in this chapter, most interfaces for VR environments limit the presentation of the stimuli to just the surface of the user's hands. However, the aim of a fully immersive VR system should really be to present information across the user's entire body surface (or at least over a substantially greater surface area than merely just the fingertips). Note, in fact, that beside our manual interactions with 3D objects in our everyday activities (from walking on the street to reading a book while sitting on the sofa) tactile sensations continuously arise from the all parts of our body. From the point of view of body motion, inserting a whole body mimicking the movements of most of our body parts into a simulated environment is technically feasible. However, this requires a large space and several cameras that can track and continuously compute (without significant delay), the position of our joints within such a space. The technology to do this is already available, although generally limited (at least at present) to a few laboratories and research centers (e.g., Davison, 2001; Ribeiro, Sole, Abbott, & Milosavljevic, 2011). By contrast, the stimulation of touch across the entire body surface, requires the deployment of extremely cumbersome and bulky exoskeletons, that are able to provide force feedback to any of our body parts, as well as of systems able to stimulate each class of tactile receptors on our skin (with the intensity and quality required by each different part of the body).

At the moment, the technology is far from being able to deliver a full-body interface device. Note also that the presence of an exoskeleton can't always be compatible with the systems necessary to deliver tactile stimulation to the surface of the body (because of the point of contact between the exoskeleton and the skin) as well as requiring an incredibly high mechanical complexity in a very small space in order to simulate movements with the required degrees of freedom (think only about simulating the movements of a ballet dancer with such a device). That is, one of the major problems related to the development of a full body exoskeleton relates to the fact that the functioning of any mechanical device (such as the actuators within a force feedback system) is always going to be associated with the presence of friction (e.g., Colgate, Stanley, & Brown, 1995), something that is not necessarily present in many real-life situations. Indeed, our bodies move through air and are generally not connected to any external mechanical system. However, within a VR environment, an operator might perceive the presence of an external device, rather than concentrating on the actual stimulation provided, because of the presence of this unavoidable mechanical limitation.

A viable alternative to exoskeletons might be the adoption of devices that are capable of simulating forces by means of magnetic fields (allowing complete freedom by moving objects through empty space and an absence of unwanted friction; e.g., Lee, Post, & Ishii, 2011). Unfortunately, however, so far these devices seem to have been confined to the simulation of simple fingers movements mediated by a probe. For example, in the magnetic levitation haptic interface (named Maglev 200) by Butterfly Haptics (<<http://butterflyhaptics.com/>> downloaded on October 10, 2012), the user grasps a handle attached to a 3D object (a "flotor") levitating within a strong magnetic field. The handle can be moved with six degrees of freedom within the field sending

position and orientation information to the user's application. Whether or not this kind of technology can be applied to full body movements in the future is more in the realm of fiction than in that of science.

That said, the massive technological limitations highlighted in this chapter have certainly not prevented a number of companies and researchers from attempting to design devices that are capable of simulating the presence of the entire body surface in a VR setting. One of the earliest attempts to create a simulation involving stimulation presented over different body parts and involving more than one sensory modality at the same time, was the "Sensorama," developed (and then patented) in 1957 by the man who is acknowledged as "the father" of VR, Morton Heilig. This device consisted of a machine in which the user was presented with 3D images, smells, stereo sound, wind, and vibrations (see Heilig, 1962, 1992; see Figure 9.1). A few films (or one might say "simulations") were made especially for Sensorama. In one of these, the user was able to experience a motorcycle ride through Brooklyn. The sense of presence was enhanced by blowing wind through the user's hair, by presenting the sounds and smells of the city, and by simulating bumps in the road by means of a vibrating chair. The Sensorama was certainly brilliantly intuitive. However, the fact that it was initially designed for use in cinemas probably contributed to its negative fate. In fact, one may only wonder how many of us are likely to enjoy the experience of being in a cinema trapped in a box without any possibility of interacting with those around us.

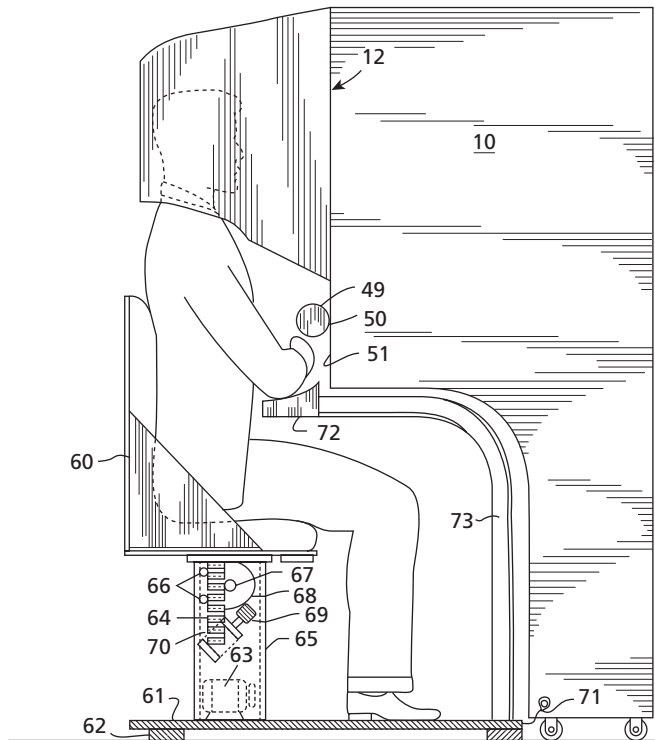


Fig. 9.1 The Sensorama machine by Morton Heilig (see Heilig, 1962). Figure 5 of U.S. Patent #3050870 (via <<http://patft.uspto.gov/>>). Date=Filed January 10, 1961. Author=Morton Heilig.

A few devices that are capable of simulating the entire body surface have also been developed in more recent times. For example, the company “VirtuSphere” has developed a unique VR sphere made of ABS plastic and polycarbonate which allows a user to walk, jump, and even run while wearing special wireless VR glasses (<<http://thefutureofthings.com/pod/199/virtual-reality-real-pain.html>> downloaded on March 19, 2010). Currently, the VirtuSphere weighs somewhere in the region of 200–220 kg, stands 2.6–3.0 m high, and costs an estimated 50,000–100,000 US Dollars! Although designed for multiple applications, such as military simulations and gaming, one cannot help but wonder how many people will have the space, never mind the money, to place such a cumbersome device within their own homes. Note also that within the virtual sphere people can move their entire body and walk around the simulated environment (thus overcoming some of the limitations of other applications), but force feedback as well as tactile stimulation of the entire body surface is not provided.

It is important to note here that despite the constraints seen so far (and until the problem related to providing complete force feedback to a greater number of parts of the body has been solved), the goal of achieving full-body virtual touch (Iwata, 2008) might be less challenging than expected (see Dennett, 1991, for one philosopher’s pessimistic early view of the possibility of virtual tactile stimulation). Why? Well because scientific research has shown that: (1) Tactile receptive fields are larger on certain areas of the body (e.g., the back) than others (e.g., Weinstein, 1968). Consequently, a smaller number of stimulators can be used on those parts of the body that have a lower sensitivity in order to simulate the presence of a given object; and (2) People do not appear to be aware that multiple stimuli are being presented on their skin (regardless of whether they are presented on the fingertips or on the rest of the body surface) whenever more than three stimuli are presented at the same time (e.g., Gallace, Tan, & Spence, 2006a, 2008a; see also Chapter 4, for a discussion of the limitations on tactile information processing). This is likely due to the fact that when multiple stimuli are presented, we simply can’t (at least not without a great deal of practice) attend to more than two or three of them at once (unless, perhaps, the stimuli are somehow related to form intuitive patterns). Moreover, it is also possible that, under certain conditions of stimulus presentation, the available information is automatically organized into patterns and/or perceptually “completed” (e.g., Gallace & Spence, 2009; see Chapter 3). That is, when more than two fingers are concurrently stimulated we might feel more like having an object in our hand, than feeling separate sensations on each finger (see Gallace & Spence, 2011; O’Regan, 1992).

Therefore, it might be possible that stimulating only a limited number of body positions would result in the perception of more complex perceptual patterns, even without the need to provide more complete (and resource-consuming) high-resolution stimulation across the entire body surface (cf. Dennett, 1991). This factor might be even more relevant when any lack of tactile stimulation happens to be compensated for by the presence of consistent information from other sensory modalities. Moreover, these observations also suggest that given the limited number of stimuli that people can perceive when presented at the same time, VR should provide only that information that is strictly relevant to the task at hand and/or that users are more likely to attend to. That is, we do not always feel the presence of the clothing on our skin or of the chair in which we happen to be sitting (at least if we do not concentrate on these aspects of our tactile milieu; Graziano et al., 2002; see Holmes & Spence, 2006, for a review). Therefore, providing this additional information within a complex virtual scenario would likely be of little use (and even deleterious in terms of bandwidth limitations).

Generally speaking, we are generally fully aware of changes in the available information (given the fact that “transients” automatically capture our attention), but not necessarily of those parts

of a scene that remain constant over time (e.g., Gallace Tan, & Spence, 2006b; Simons & Levin, 1997). Once again, these considerations from the extant cognitive and neuroscientific research on human information processing suggest that, within a virtual environment, it is only really necessary to render a small percentage of the available information (for example, that concerning stimulus transients) in high definition in order to elicit a given percept. In fact, the same principle has already been exploited in visual displays, where the amount of rendering on the screen can be adapted to the visual information processing capacity of the observer (e.g., Watson, Dayal, Luebke, & Woolley, 2004). That is, higher-definition images can be used solely in those portions of the screen where the user's gaze is directed (see Duchowski, Cournia, & Murphy, 2004). As far as haptic rendering is concerned, more financial as well as human resources have been devoted to the study of this topic over the last few years. These efforts are a direct realization of the fact that in order to simulate correctly a given situation or object that has to be manipulated by the user, a good rendering of its surface characteristics needs to be achieved. This can be the case for the simulation of human organs to be used in virtual surgery (e.g., Mastmeyer, Fortmeier, & Handels, 2012; Zhu & Gu, 2012; see section 9.2), as well for the simulation of new cars or pieces of furniture (e.g., Kuchenbecker, 2008; Strolz, Ehinger, & Buss, 2009; cf. Dai, 2011). Moreover, given that one of the most expensive (both financially and environmentally) processes when it comes to designing new objects nowadays relates to the creation of prototypes, people have started to realize that virtual prototyping might be a viable option to sensibly reduce these costs (e.g., Bordegoni, 2011; Bordegoni & Cugini, 2010; Bordegoni, Cugini, Caruso, & Polistina, 2009; Seth, Vance, & Oliver, 2011). In fact, manufacturing companies, engineers, and designers can now use virtual prototyping to explore the performance and perceptual appeal of a huge number of VR design alternatives of the same object investing only a tiny fraction of the time and money required to build actual prototypes. However, in order to be effective, virtual prototyping needs to provide engineers and designers, as well as eventual panels of those testing the prototype, with the possibility of correctly simulating those sensations that are important for the development and appreciation of the objects to be simulated. That is, designers need tools that allow them to convey their ideas regarding the technical as well as perceptual quality of the product that they wish to create. Many of these qualities involve the sense of touch.

Designers working with real objects often use tools like rakes and sandpaper, sweeping and scraping material in order to model the shape and surface of their prototypes (e.g., Yamada, 1997). Then they need to haptically check the quality of the surface of the object and eventually to finish it using additional (and more precise) tools. There have been many attempts to reproduce these tools and the interactions with the object that they allow one to create within a virtual prototyping environment (e.g., Bordegoni & Cugini, 2010; Bordegoni, Cugini, & Ferrise, 2012; Bordegoni, Ferrise, Covarrubias, & Antolini, 2011). However, the virtual counterpart of these tools are often designed by analyzing (and then attempting to reproduce) the movements of the hands performing a given task (or, more often, the forces involved in the action), sometimes leading to a lower weight given to the more cognitive, emotional, and perceptual aspects related to the use of the tool (e.g., Bergamasco, Frisoli, Gucciardino, & Marchese, 2003; Cugini, Bordegoni, & Giraudo, 2010). These aspects become even more important when the virtual prototypes need to be tested on the final potential users (who are not necessarily engineers, and do not generally talk about forces, but more often about perception and the beauty of objects). A failure to correctly reproduce the perceptual qualities (be they haptic, visual, or multisensory) of a virtual prototype might then result in an object being produced that does not contain those qualities that are more effective in eliciting certain perceptions or emotional responses in the end user. That is, we believe that, in order to be effective, haptic prototyping and haptic rendering should be more firmly based

on our knowledge regarding how tactile information is processed by our neurocognitive system and how this information elicits a variety of emotional and aesthetic responses in the user. In certain cases, this knowledge might result in a facilitation of the design of a virtual prototyping interface. In particular, note that our evaluation of a haptically explored surface can be affected by the simultaneous presentation of visual or auditory information (Guest et al., 2002; Guest & Spence, 2003a, b). That is, the adoption of multisensory displays might compensate for the higher complexity required to correctly render haptic and tactile information in virtual prototyping (e.g., see Lee, Poliakoff, & Spence, 2009).

9.4 Augmented reality in touch: A tool for facing sensory deprivation and decline

AR can be defined as the enhancement of one's current perception of reality by means of additional information provided by computers (e.g., Azuma, 1997). AR is well differentiated from VR, given that the former does not require the replacement of real with virtual information, but solely the increase (or even the decrease in some cases) of the amount of information that is available to the user (e.g., Bimber & Raskar, 2005; Fuchs & Ackerman, 1999). For example, an AR interface can provide distances, dimensions, descriptions, or GPS coordinates of real objects or features seen through special goggles or screens while driving or walking (e.g., Brown, 2011). AR can be used to superimpose visual information over a tangible object (such as a piece of furniture, an electrical appliance, or even shoes and clothing) in order to change its appearance while leaving constant its functionality and tactile quality (e.g., Mottura, Greci, Travaini, Viganò, & Sacco, 2007). While the use of visual AR is gaining more and more weight in a number of situations, the development of haptic and tactile AR seems to be moving much more slowly.

One can only imagine the potentialities of augmented touch. Think, for example, about the possibility of reading a medical book and being able to experience how a swollen gland feels to the touch, or having the possibility of feeling the fabric of a dress when watching its image on the Internet (note that visual AR can already provide the possibility of "trying on" clothing—by superimposing them to real images of your body taken from a videocamera—before buying them; see <http://www.readwriteweb.com/archives/retailer_lets_online_shoppers_virtually_try_on_clothes_using_augmented_reality.php> downloaded on October 3, 2012; Ho, Jones, King, Murray, & Spence, 2013). By means of haptic AR, a mother might, for example, be able to touch her unborn child in the womb. Great advantages might also come from experiencing contacts with objects that aren't manipulable at their actual scale. That is, one might think about the benefits that nanotechnologists might get from the possibility of fully interacting with nanotubes or even smaller structures by means of haptic AR (see Tan, Walker, Reifenberger, Mahadoo, Chiu, Raman, Helser, & Colilla, 2005, for a discussion of this point).

A number of pioneering attempts to provide haptic AR to users can be found in the literature (e.g., Harders, Bianchi, Knoerlein, & Szekely, 2009; Jeon & Choi, 2009, 2011). In particular, a recent and promising project involving haptic AR has been developed by the Disney Research center in Pittsburgh (see <http://www.disneyresearch.com/research/projects/hci_revel_drp.htm> downloaded on September 27, 2012). The authors of this study developed a device named REVEL that enabled the user to change the feel of any real surface and object, comprising walls or pieces of furniture (see Bau & Poupyrev, 2012). By using this system, when moving their fingers on the surface of the object, the user should be able to perceive distinctive tactile textures that augment the characteristics of physical objects. The REVEL system is based on the "reverse electrovibration" principle. That is, a signal generator, triggered by a context-sensing system, creates various

tactile sensations by applying an electrical signal to the user's body. As a consequence, when the user moves their fingers over the surface of a physical object, he/she should be able to feel virtual tactile textures (only when the fingers touch virtual content overlaid on the physical object). Varying the properties of the signal, such as its shape, amplitude, and frequency, should result in a wide range of tactile sensations. That is, such a device should allow for tactile sensations to be superimposed over external objects, thus changing the user's experience of them. Note, however, that in order for REVEL to work properly, the surface of the object that is being touched by the user must be conductive and covered with a layer of insulating material, a limitation that, we argue, might well be expected to compromise the commercial success of such systems. Moreover, extensive psychophysical testing will be needed in order to verify the quality of experience that can be obtained by using this device. At the moment, it sounds to us like one of the many interesting ideas still waiting to be proved before it becomes a part of future technology.

Importantly, tactile AR should not only provide additional information within a real context, it might also be used to compensate for the sensory decline that occurs throughout the lifespan (see Kalisch, Kattenstroth, Kowalewski, Tegenthoff, & Dinse, 2012, for the decline affecting haptic performance). A number of aids for visual and auditory decline can be successfully used, but the decline of tactile sensations would seem (at least to date) to have been left to its own fate. Tackling this problem is even more relevant given that one increasingly common complaint of the growing elderly population is the fact that no one wants to touch them (i.e., there is a lack of tactile contact; e.g., Field, 2001). Excluding the TVSS systems discussed in section 9.6, no device has yet been explicitly developed in order to augment touch for the elderly. As a consequence, this field of research, despite its great potential, is still largely unexplored.

9.5 Touch screens, touch devices, and tactile user interfaces

A few years ago, a number of the mobile phone companies started to commercialize mobile phones equipped with voice recognition technology (see Tobak, 2007, for the observation that voice recognition devices were classified in 2007 as “the biggest disappointment of all” in the top ten of technology flops!). That is, the user could simply say the name of the person to be called in order for the phone to automatically dial the correct number. At the time, that was considered a major innovation with respect to frenetically moving your thumb over a tiny keyboard in order to perform the exact same operation. Surprisingly, though, this technology never caught on among mobile phone users (and, at least to our knowledge, still hasn't, despite the greater efficiency of voice recognition technologies, as well as the amount of financial support given to this sector)!² By contrast, over the course of the last decade or two we have witnessed a steady and rapid migration toward touch-screen technologies, which seem to be appreciated much more by the end users. One might argue that while interacting with objects is something more germane to our sense of touch, speaking to objects is still not perceived as a natural way of controlling external devices. In fact, our ability to haptically explore external stimuli and interact with other agents develops well before our ability to use language (e.g., Hertenstein, 2002; Muir, 2002). That is, our

² One might wonder if the release of mobile phones able to simultaneously translate a person's speech in different languages will catch the interest of mobile users in the years to come. See <<http://www.geek.com/articles/mobile/google-working-on-instant-speech-translation-for-cell-phones-2010028/>> downloaded on October 23, 2012.

very first interactions with the world, be they social or perceptual, are indeed mediated by tactile contact rather than language (e.g., Castiello, Becchio, Zoia, Nelini, Sartori, et al., 2010; Streri & Spelke, 1988). It is, then, not so surprising to see that people prefer to engage into more physical forms of contact with external objects, leaving language to the domain of social interactions. Perhaps making the device more human (in its appearance or in terms of the responses provided) will change this trend in the future, but so far, touch screens seem to largely have superseded vocal recognition technology in our ways of interacting with objects.

Touch-screen technologies now allow an operator to press buttons, turn pages, enlarge objects, and to accomplish a larger range of operations than ever before. The possibility for the users to execute these operations, that somehow mimic their natural way of interacting with objects, has certainly contributed to the success of touch-screen devices such as the iPhone or Kindle. In fact, we would like to argue that when a device is designed in a way that is compatible with the human neurocognitive architecture (that is, the way in which our brain processes information and responds to it) is certainly more likely to win the competition for marketing success. From the point of view of the functioning of the cognitive systems, touch screens appear to offer a number of advantages relative to other technologies. In particular, they allow for a spatial alignment among visual, tactile, and auditory signals to occur. That is, in order to open my SMS mail box, one can press an icon representing an envelope on one's mobile phone touch screen. My touch activates a sound (providing feedback about my action) that arises from pretty much the same position as the mail box one the screen (at least at a perceptual level). All of this convergence of multisensory information certainly contributes to the intuitiveness of using such a device (see also Chapter 10).

Beside the many advantages of touch-screen devices, a few negative points should also be considered. In particular, pressing a button on a touch screen does not feel like pressing a real button. That is, no tactile feedback regarding a change in the status of the button is provided, thus leading many users to prefer devices where physical buttons are provided (what in the users' dispute regarding the individual preference for iPhone or Blackberry mobile phones was defined as the "I type faster on my BlackBerry" argument; see <http://www.geek.com/articles/apple/apple-patents-tactile-feedback-on-a-touchscreen-2011046/> downloaded on 3/10/2012). Moreover, the response of the button on the screen depends on the pressure that is exerted over a specific area of the screen that does not necessarily coincide with the visual appearance of the button. This might lead to problems, especially when older and/or sensory-motor impaired people are concerned (e.g., Sesto, Irwin, Chen, Chourasia, & Wiegmann, 2012). A number of companies and researchers are currently trying to fix these important limitations. As a consequence, technologies that are capable of providing tactile feedback to the user directly through the surfaces of the touch screen have now started to be developed and patented (see for example the "Keystroke tactility arrangement on a smooth touch surface," recently patented by Apple; see <http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetachtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=7,920,131.PN.&OS=PN/7,920,131&RS=PN/7,920,131> downloaded on October 3, 2012).

As briefly mentioned in the introduction to this chapter, another tactile technology that is now a constant feature of mobile phones relates to vibrating devices. These relatively simple systems inform us about incoming calls or messages, as well as playing the role of silent alarms in those situations in which delivering auditory signals might be forbidden or inappropriate (such as during meetings or in cinemas, libraries, and other public places). These devices are also thought to be effective in those environments in which the overall level of acoustic noise is too loud for a small loudspeaker, such as that contained in a mobile phone, to be heard. Despite the clear

advantages that can be obtained by providing information to mobile phone users by means of the sense of touch, a few problems should also be highlighted. A first issue relates to the alerting capability of the tactile sense in those situations in which the other senses are also stimulated (see Chapter 10 for further discussion of this point). That is, is it really true to say that a person will always note a tactile vibration coming from his or her pocket when standing in a crowded party, perhaps drinking a martini or munching on some snacks, listening to music and chatting with other people? That is, when the sensory as well as attentional systems of the user are overloaded by the incoming signals (regardless of their sensory modality), one might reasonably hypothesize that much higher-intensity vibrations (perhaps even outside the capability of the instrument to produce them) will be needed in order to be noticed (see Shirazi, Holleis, & Schmidt, 2008; see also Chapter 4, for the failure to notice vibrotactile stimuli).

Interestingly, vibrating devices can be inserted in a whole series of interfaces. In fact, an instrument capable of providing tactile feedback to PC users was advertised and marketed by Logitech in 2000: the iFeel mouse. This device can provide vibration feedback whenever the mouse moves onto a clickable object on the PC screen, be it a window or an icon. It can also vibrate when the user performs tasks such as sizing a window or moving a scroll bar. The fact that this device, as far as we know, isn't on sale any more is perhaps suggestive of the fact that tactile feedback is useful only when it really reproduces the interactions occurring with objects in a natural context (that is, whenever people touch buttons or objects in real life they do not get vibrations from them).

Another problem when using vibrating devices is certainly determined by the fact that mobile phone users are likely to be on the move when they receive an incoming call or message. However, many studies have demonstrated that the execution of bodily movements decreases a person's sensitivity to detecting tactile stimuli presented on their body, a phenomenon known as "sensory suppression" (e.g., Chapman & Beauchamp, 2006; Cybulska-Klosowicz, Meftah, Raby, Lemieux & Chapman, 2011; Juravle, Deubel, Tan, & Spence, 2010; Juravle, Deubel & Spence, 2011; Juravle & Spence, 2011; Voss, Ingram, Haggard, & Wolpert, 2006; see also Gallace, Zeeden, Röder, & Spence, 2010, for the observation of this phenomenon in a simulated driving task). Following on from this observation, one might think that a mobile phone vibration is likely to decrease its alerting power when the user is moving. Therefore, in order for vibrating devices to be more effective, the developers should implement additional systems able to vary the intensity of the vibration as a function of the user's degree of motion.

Importantly, a number of studies on sensory suppression have demonstrated that the ability of an individual to detect tactile stimuli decreases as a function of the distance between the moved body part and the position where the tactile target stimulus is presented (e.g., Williams, Shensasa, & Chapman, 1998). Following on from this result, one might think about the possibility of installing the vibrating device of mobile phones or tablet PCs, on a body position that rarely moves (such as, for example, the ear).

Taken together, the observations regarding the limitations affecting the use of the tactile devices mentioned in this section seem to strengthen our suggestion that, in order to be part of our everyday life, technologies have to comply with the neurocognitive architecture and limitations of their end users.

9.6 Tactile sensory substitution systems

In the 1970s, following on from the studies sponsored by the US army regarding the possibility of presenting "silent" information to soldiers, novel devices, known as "tactile vision substitution systems" (TVSS) were developed (see Chapter 1). These devices enable a visual

image to be scanned by a camera and then converted by electronic circuits into 2D patterns presented to the skin by means of a more or less complex matrix of tactile stimulators (i.e., a 20×20 matrix of 400 tactile stimulators in the first studies to have been reported in this area; e.g., Bach-y-Rita & Collins, 1969; Collins, 1970; see also Williams, Ray, Griffith, & De LAune, 2011). The most relevant application of these devices was to re-establish the perception of distal objects in those individuals who were visually impaired. In fact, a number of studies conducted in the early 1970s were designed to address (assess) the ability of visually impaired individuals to interpret visual information presented to the skin by means of such devices (e.g., Bach-y-Rita, 2004; Bach-y-Rita & Collins, 1969; Collins, 1970; Craig, 1973; Linvill & Bliss, 1966; White et al., 1970).

Extensive research has demonstrated that participants can use such TVSS devices to correctly and “intuitively” perceive simple patterns of stimulation, such as vertical, horizontal, and diagonal lines. By contrast, only expert and well-trained users could identify common 3D objects or faces (e.g., Bach-y-Rita, 1972). Performance among individuals trained to use these kinds of devices varied greatly, but it was demonstrated that a few experts were actually able to assemble electronic material presented under a microscope using TVSS (see Bach-y-Rita, 1974). The poor spatial resolution of the surface of the skin (as compared to the retina), however, prevented the TVSS from ever being used successfully for tasks such as the exploration of visual environments or navigation (though see Segond, Weiss, & Sampaio, 2005).

It is also important to note that since the first studies on the effectiveness of these devices were conducted, it soon became clear that people had to exert some degree of control over the acquisition devices in order for the substitution to occur. In fact, within the first TVSS system, the camera transmitting the signal to be translated was mounted on a stand in front of the visually impaired participant. Those using this system reported that no perception of distal objects was possible unless they could hold the camera and actively move it (e.g., Guarniero, 1974, 1977). That is, a sort of coordination between motor and sensory processing was required for the appropriate percepts to arise. Note also that by using these procedures the participants spontaneously reported the stimuli as being localized in external space, from a position in front of the camera, rather than from the vibrotactors placed on their back. That is, “distal attribution” of sensations was apparently achieved. Moreover, the participants reported that the quality of the sensations experienced was not classifiable as a kind of touch. This is how a participant (a doctoral candidate in the Department of Philosophy at New York University) in the early TVSS experiments described his experience: “The visual cortex of the brain, it should be stressed, was not involved in the interpretation of the sensory inputs received from the device. Although the somatosensory cortex, only, was involved, nevertheless the experienced quality of the sensations was nothing like that perceived by touch. Rather than coining a new word, or using ‘touch’ or ‘feel,’ I shall use the word ‘see’ to describe what I experienced” (Guarniero, 1974, pp. 101–102). Such observations led the authors of the first studies in this area to suggest that the use of TVSS systems resulted into a sort of “tactile vision” (see Bach-y-Rita, Collins, Saunders, White & Scadden, 1969; see also Guarniero, 1974, 1977; though see Auvray & Myin, 2009, for a critical view concerning whether sensory substitution might be equivalent or reducible to an already existing sensory modality).

Here it is relevant to note that although the very first TVSS devices were designed to stimulate the user’s back, it became clear over the years that higher-definition “tactile vision” could likely be achieved only by presenting stimuli to areas of the body endowed with greater tactile sensitivity. In particular, new devices were built, that were capable of presenting information to other body areas such as the participants’ forehead (e.g., Kajimoto, Kanno, & Tachi, 2006) and tongue (e.g.,

Sampaio, Maris, & Bach-y-Rita, 2001). As far as the tongue is concerned, there are a number of advantages associated with using this part of the body surface. In particular, a device mounted there is protected by the oral cavity and the saliva in the mouth provides a good electrolytic environment requiring just 3% of the voltage needed for stimuli presented on the fingertips (note that electrotactile and not vibrotactile actuators were used with such interfaces). Moreover, the high numbers of neural receptive fibers that innervate the tongue (see Chapter 2) allows for the construction of smaller arrays (as compared to other body parts) with large numbers of transducers (thus resulting in greater image resolution).

In addition to substitute visual signals, tactile substitution systems mounted on the tongue were tested on participants with bilateral vestibular dysfunction (a condition that prevents the patient from maintaining an upright orientation of their body without constant visual control). In this case, the user was supplied with information regarding the orientation and motion of his/her head or body with respect to the gravitational vertical by means of electrotactile stimulation on his/her tongue (e.g., Tyler, Danilov, & Bach-y-Rita, 2003; Vuillerme, Pinsault, Fleury, Chenu, Demongeot, Payan, & Pavan, 2008). Even if the results obtained by using this device as an aid for balance rehabilitation training or for assisting daily activities in vestibular-impaired individuals, would seem to be very promising (see Vuillerme et al., 2008; see also Priplata, Niemi, Harry, Lipsitz, & Collins, 2003, for a vibrating device implanted in the soles of the shoes worn by the elderly to improve balance), a number of problems related to its acceptability (note that the wearer of these devices cannot speak or eat while using them) and its hygiene following repeated usage still needs to be tackled in order for them to be widely adopted by users. This also leads to the suggestion that these devices might perhaps be more successful for short-lasting military operations where these problems are not a major issue (see <http://news.nationalgeographic.com/news/2006/05/0501_060501_tongue.html> downloaded on October 15, 2012).

In general, despite their potential, what is most striking after four decades since their introduction is how little impact such devices have made on the lives of those who might potentially benefit from them. One of the few TVSS devices that has survived over the years and obtained a relatively large commercial and applied success is the “Optacon” developed by Bliss, Katcher, Rogers, and Shepard (1970). This device converted printed letters scanned by a camera to vibrotactile patterns of stimulation presented to the fingertips and was reported to allow expert users to read up to 90 words per minute (Hill, 1973; see also Craig, 1977). By contrast, the large majority of the early devices failed to capture a significant market share (despite the efforts and sometime the too optimistic claims of scientists like Paul Bach-y-Rita who dedicated their lives to research in this field). It has been suggested that this negative outcome might have been due to the fact that too much attention was given to precisely acquiring information from one sensory modality (e.g., vision or audition), while less effort was dedicated to verifying how accurately the substitution process was successful (e.g., Brayda, Campus, Chellali, & Rodriguez, 2010). Moreover, the lack of attention to the more central (in addition to peripheral) aspects of tactile information processing in early studies on this topic (see Chapter 4), as well as the relatively low bandwidth that characterizes the tactile channel (see Gallace et al., 2011), are certainly other aspects, that in our opinion at least, have contributed the most to this apparent failure.

More recently, TVSS systems have been adopted to provide information not only to visually impaired individuals but also to sighted participants. For example, attempts have been made to provide stock market information regarding current transactions through a pair of “haptic shoes” equipped with vibrators inserted into the soles (Fu & Li, 2005). Even if the authors of this particular study acknowledged that “[at least] in the early stage, the capacity of this approach

may not be as powerful as visual methods” one might argue that presenting vibrations to the feet can be somehow more alerting and less open to interference (especially in a crowded room) than presenting information to other parts of the body. Still, the lack of intuitiveness in stimulating the soles of a person’s feet might be expected to have a detrimental effect on the amount of cognitive resources required to interpret the signals received. That is, we suggest that such a device might be more effective in providing simple spatial information to walkers (e.g., navigational information from a GPS system, say), than in providing complex information requiring fast reactions such as indicated by stock market changes.

Not only can visual or auditory sensations be substituted by touch. Pain is also an additional candidate for substitution. Pain, by minimizing immediate harm by motivating escape (e.g., Auvray, Myin, & Spence, 2010; Darwin, 1872; Melzack & Wall, 1965), plays a major role in our life. In fact, the failure to rapidly react to noxious stimuli might cause damage to our body and even death (see also <<http://www.bbc.co.uk/news/health-20239836>> downloaded on November 8, 2012, for the extreme difficulties experienced by those patients affected by congenital analgesia, a condition that prevents them from feeling pain; e.g., Manfredi, Bini, Cruccu, Accornero, Berardelli, & Medolago, 1981). As a consequence of its importance, and despite the fact that most of us want to get rid of the sensations generated by noxious stimuli, there is much interest in substituting this sensory modality in a variety of different scenarios. For example, just as we have seen for visually impaired individuals, one might want to replace the lack of pain in those individuals who lost this sensory capability by means of tactile signals.

There are certainly many situations in which pain is needed in order to increase the realism of VR simulations or games. This is, for example, the case of soldiers training on combat procedures or of PC gamers playing war videogames such as *Call of Duty*. In all of these situations, even if pain is an important part of the action, harm to the body has to be prevented. As a consequence, one might want to substitute pain by means of other sensory signals and the best option here might be to use the tactile sense for this purpose. In fact, in contrast to vision and audition, touch, just as for pain, is a contact sense (see Fabrizi, Slater, Worley, Meek, Boyd, Olhede, & Fitzgerald, 2011, for the development of neural circuits necessary to discriminate touch from pain in infants aged 28–45 weeks of gestation). Moreover many scientific studies would now seem to suggest that they are processed, at least up to a certain extent, in a similar way by the brain (see Gallace, Torta, Moseley, & Iannetti, 2011). One might, however, wonder whether substituting pain is really a viable option in terms of activating in the user the same, or at least similar, emotional and cognitive reactions as those generated by the real stimulation of this sense. In particular, it has been claimed that nothing is so effective as pain in terms of capturing our attention (see Spence, Bentley, Phillips, McGlone, & Jones, 2002). How can a poke on the shoulder be effective in driving your thoughts away from your current action, just as a bullet or a knife hitting your body would be? Will you notice it at all while pulling the trigger of a M16A2 rifle playing *America’s Army*?

A few attempts have been made by researchers to substitute pain sensations via tactile devices, for example, in patients affected by leprosy. These patients experience an absence of feelings of pain in their leprosy member. This absence of sensation often results in serious damage to the body. In 1969, Brand and Ebner developed a prosthetic system that could be attached to the patient’s affected body part, and which could substitute pain by means of pressure stimulators (see also Brand & Yancey, 1993). The results of this study, the first of its type, revealed that these devices were of little use for the patients concerned. This was due to the fact that the patient, when stimulated by the new stimuli, did not feel the urge to react to them, just as required by a really painful stimulus. As a consequence, those tactile stimuli were soon largely ignored. That is,

tactile sensations were totally ineffective in substituting painful sensations, due to the completely different nature (and, in particular, the different “qualia” generated by them) of these two sensory modalities.

Not surprisingly, the gaming industry has also tried to increase the realism of videogames by providing their gamers with the possibility of feeling shots, stabs, slams, and hits dealt to their on-screen characters/avatars, without actually harming their body. For example, the 3RD Space Vest (<<http://tngames.com/>> downloaded on October 5, 2012) uses air to generate impact and pressure forces on the body. The developers claim that this device can emulate the quality, character, and positional attributes of what is seen on the screen. That is, this device is thought to allow the user to feel the impacts of bullets or the explosion of grenades in war games from the position where they actually occur. Note, however, that while feeling the vibration generated by an explosion just behind you is likely very effective in enhancing the realism of the game, the problem related to the fact that tactile sensation might be more easily ignored than their noxious equivalent still remains. This is probably the reason why, thus far, few attempts have been made to directly add pain to videogames. For example, an arm-wrestling system that delivered electric shock to the loser was designed for just this purpose (see <<http://www.electrics Shock.org/electric-shock-games.html>> downloaded on December 17, 2012; see also Kitami, Yamamoto, Kano, & Tsutsumi, 2002, for the concept of arm-wrestling in robotic interfaces). The reader may vaguely remember a fictional version of this device that appeared in the 1983 movie, *Never Say Never Again*, where Maximillian Largo (Klaus Maria Brandauer) challenges James Bond (Sean Connery) in a video game which delivers a painful electric shock to the loser. The question for video-makers, then, becomes will people really buy and play with videogames where unpleasant painful sensations are a real part of the action? As far as this point is concerned, one might wonder whether there are alternatives for generating the reactions and emotions elicited by noxious stimuli in humans, that do not necessarily involve substituting pain by tactile sensations (ineffective), or using real painful stimuli (that might end up harming the user). One possibility here comes from the use of thermal illusions. In particular, in the “thermal grill illusion,” the participants experience a sensation of burning heat when touching with the hand a grill made of interlaced warm (40° C) and cool (20° C) bars (e.g., Bach, Becker, Kleinböhl, & Hölzl, 2011; Bouhassira, Kern, Rouaud, Pelle-Lancien, & Morain, 2005; Thunberg, 1896).

So far in this section, we have discussed the substitution of a given sensory modality (e.g., vision) with information from a different sensory modality (e.g., touch), however, an even more advanced field of research aims at recreating the original sensations when they are lost or unavailable. This is the case of neuroprosthesis for amputees or patients suffering from peripheral nerve damage and spinal cord injuries (e.g., Abbot, 2006). This is a relatively new field of research and, in fact, while sensory substitution systems for the restoration of hearing and vision have been developed and investigated for several decades, it is only in the last few years that neuroprostheses that are capable of combining motor and sensory components have started to be tested (e.g., Marzullo, Lehmkuhle, Gage, & Kipke, 2010; O’Doherty, Lebedev, Hanson, Fitzsimmons, & Nicolelis, 2009).

A neuroprosthesis is a device, or series of devices, that can substitute the functions performed by a motor, sensory, or cognitive system (see Handa, 2006). For example, a cochlear implant (one of the first neuroprosthesis to become widely available for sensorially impaired patients; e.g., House, 1976; Pialoux, Chouard, & Macleod, 1976) is able to substitute the function of the damaged internal organs of the ear. It performs this task by using a microphone that captures external sounds and processes them by means of a frequency analysis similar to that performed in the cochlea. The result of this analysis is then transferred to an additional implanted unit that

directly stimulates the auditory nerves. Neural prosthesis are available for auditory, visual, and motor impairments (e.g., Ethier, Oby, Bauman, & Miller, 2012; Massida, Belin, James, Rouger, Fraysse, Barone, & Deguine, 2011; Piedade, Gerald, Sousa, Tavares, & Tomas, 2005; van den Brand, Heutschi, Barraud, DiGiovanna, Bartholdi, Huerlimann, Friedli, et al., 2012). Note, however, that the real challenge in this field of research is to create prostheses that are “bidirectional,” that is, that can allow the perception of sensory signals as well as the motor response to those signals. This is, for example, the case with robotic limbs where information from prosthetic sensors is directly delivered to somatosensory areas of the brain, and brain activity can directly control the movement of the prosthesis (see Lebedev & Nicolelis, 2006; Nicolelis, & Lebedev, 2009, for the concept of “brain–machine interface”).

In the last few years, arrays of microelectrodes have started to be implanted in the somatosensory cortex of animals, such as rodents and monkeys with the aim of understanding their effectiveness in eliciting sensations that can lead to specific patterns of action (e.g., Butovas & Schwarz, 2007; Fitzsimmons, Drake, Hanson, Lebedev, & Nicolelis, 2007; O’Doherty, Lebedev, Ifft, Zhuang, Shokur, Bleuler, & Nicolelis, 2011). In particular, in a recent study by O’Doherty, Lebedev, Li, and Nicolelis (2012), monkeys were trained to reach (by using a virtual arm towards seen through a screen) objects and search for a specific object having a particular artificial texture. The texture was indicated by a pattern of intracortical microstimulation (ICMS) on S1. The results revealed that the monkeys were able to effectively distinguish between different patterns of ICMS, leading the authors to suggest that this procedure can be used to simulate a sense of touch. Results such as these certainly constitute advances in terms of our growing understanding of how to give rise to tactile sensations by means of brain interfaces. However, a number of critical issues still need to be resolved in this area. In particular, it is unclear what kind of patterns can be used in order to recreate certain qualities of more or less complex tactile sensations (or more simply the responses to them). This is how O’Doherty and his colleagues (2012), put it: “Notwithstanding initial encouraging results, it is unclear whether ICMS would be sufficient to reproduce the rich sensory information of the world of touch. In particular, it is not well understood which kinds of ICMS patterns are most useful for virtual active touch” (p. 85). Similarly, research on this topic should also consider if and how the operation of such devices (and the reinstatement of a sensory-motor loop) could result in the incorporation of the prosthesis into the neural representation of the body (see also Chapter 8, on this point).

In summary, this section has revealed that while the substitution of visual, auditory, and vestibular information by means of tactile sensations would appear to be a viable option (although still to be refined) for providing information to visually impaired patients, the substitution of pain in both sensory impaired and normal participants does not seem to be equally effective. Finally, the promising field of neuroprosthesis seems to be still at a very early stage of development (especially as far as tactile sensations are involved) in order for clear conclusions on its effectiveness to be drawn.

9.7 Interpersonal touch in the era of virtual communication

As has been mentioned already (see Chapter 7), body contact (and gesturing) forms an important part of the information exchanged in our everyday interpersonal experiences. Unfortunately, however, these tactile aspects of communication are completely lacking in our-distance interactions (such as in telephone calls or in Internet-based communications). As pointed out by Alapack (2007), nothing, not a fantasy, nor “a text vanishing at the click of the mouse,” can compensate for the lack of flesh-to-flesh contact in virtual communication and/or relationships (see also Alapack

et al., 2005). Although many efforts have been made to ameliorate the visual and auditory aspects of on-line relationships, very little progress has been made thus far toward adding physical contact to our Internet and long-distance interactions. That is, current communication devices do not allow individuals to express their emotions through touch, body language, and/or gesture (though see the recent success of online virtual worlds, such as *Second Life*, where gestures and body language have somehow offered a further channel of communication to Internet interactions/relationships; see Ward, 2007).

One might, for example, point out that phones, web-cams, and other popular communication devices are designed for general consumption and are simply inadequate in terms of supporting and maintaining a certain level of physical intimacy between couples, relatives, or friends, who, for whatever reason, are not located in the same place. Similarly, one major criticism of “collaborative virtual environments,” has been that they lack emotional warmth and non-verbal intimacy (e.g., see Mehrabian, 1967; Sproull & Kiesler, 1986). Many researchers have therefore tried to create technological devices in order to facilitate interpersonal tactile communication. At first, the aim was to assist users with their sensory impairments, later to add another layer of information in computer-mediated communication (see Gallace et al., 2007a, for a review of the literature on technology-mediated tactile communication), or to simulate physical interaction between a human and an inanimate object. However, few projects have been explicitly designed to explore virtual interpersonal touch. One of the first attempts in this direction was the Telephonic ArmWrestling system developed by White and Back (1986). This system provided a basic mechanism that was capable of simulating the feeling of arm wrestling by connecting two robot arms over a regular telephone line. The participants who were recruited to test this device reported that they had the impression that they were wrestling a real human, although delays prevented a fully immersive wrestling experience.

It is important to note here that subjective reports, even if commonly adopted in this field, certainly do not necessarily provide a reliable means of testing the effectiveness of a given device. That is, it is now well known that people’s reports can be affected by the expectations of the experimenter, as well as by the participants’ own opinions regarding what is under test and how they should perceive it or respond to it (e.g., Rosenthal, 1966; see Levitt, Steven, & List, John, 2011; Mayo, 1949; Zdep & Irvine, 1970; for what become known as the “Hawthorne effect,” namely the change in participants’ behavior during the course of a study). Sometimes people can deliberately alter their reports or deceive the experimenter in order to prove him/her wrong (e.g., Milgram, 1963). Furthermore, participants are often unaware of the information that is provided to their sensory systems, even when able to affect their current or future behavior and responses (see also Chapter 4). That is, asking a person what is relevant for reaching a certain degree of satisfaction in using a certain device is certainly one of the worst possible ways in which to test the device itself. By contrast, more reliable psychophysical and neuroimaging techniques can provide more effective ways of answering the same question (e.g., Jeon & Choi, 2009, 2011).

Further development in technology over the course of the last 15 years or so has allowed for the construction of more sophisticated devices. For example, Dobson, Boyd, Ju, Donath, and Ishii, (2001) created a vibrotactile interpersonal communication device and a newsgroup navigation device (“Vibrobood” and “What’s Shaking”) to complement interpersonal interaction in a digital space. They found that the addition of vibration and temperature in long-distance interpersonal communication successfully facilitated the exchange of emotional and social content. For example, people interpreted a high-frequency, intense buzzing vibration as a very active newsgroup. These researchers claimed that touch (as a medium of communication) was well suited to more general concepts such as ambience, affect, and urgency, but less so for the

transmission of precise, complex information (cf. Gallace et al., 2007a). Dobson and colleagues also concluded that their mappings were so successful that no prior training was needed in order for people to successfully use the system. Moreover, such a device did not seem to require any special skills in order to be used.

Meanwhile, Basdogan, Ho, Slater, and Srinivasan (1998) conducted a series of studies in which participants used haptic devices in order to perform a collaborative task and could feel the digital avatars of one another while performing the task. Basdogan et al.'s results demonstrated that adding virtual interpersonal touch to a visual interaction improved their performance on a spatial task and increased the subjective ratings of "togetherness" (see also Sallnas, Rassmus-Grohn, & Sjostrom, 2000). Meanwhile, other researchers have tried to provide the users of instant messaging with tactile feedback. For example, Oakley and O'Modhrain (2002) developed the "Contact IM," a device designed to try and enrich current instant messaging systems by allowing users to send each other haptic instant messages. This interpersonal exchange occurred via the use of force feedback joysticks (see also Rovers & van Essen, 2004, for another example of haptic instant messaging).

Within this domain, a number of studies have investigated the possibility of using mediated social touch in order to treat certain clinical conditions (e.g., Dias et al., 2012; see Mahoney, Tarlow, & Sandaire, 1998, for an early example of mediated social interactions for Alzheimer's caregivers). For instance, Ben-Sasson, Lamash, and Gal (2012) used a shared touch-screen table in order to try and increase positive social behaviors in those children affected by autism spectrum disorder. In particular, they asked their participants to move the pieces of a virtual puzzle presented on the touch screen in either a collaborative or individual way. They found that when the participants had to collaborate in order to haptically interact with the puzzle presented on the touch screen, more social positive interactions were observed. That is, sharing action by means of haptic interactions might be effective in reducing some of the symptoms of social behavior-related disorders.

By now, many devices have been developed in order to try and maintain physical contact and intimacy for couples in long-distance relationships (e.g., Brave & Dahley, 1997; Chang, Koerner, Resner, & Wang, 2002; Gibbs, Howard, Kjeldskov, Vetere, & Satchell, 2006; Gibbs, Vetere, Howard, & Bunyan, 2005; Motamedi, 2007). For example, the aim of the "inTouch" device developed by Brave and Dahley was to try and create the illusion that two people, separated by distance, were interacting with a shared physical object. Each user of this system (which consisted of three cylindrical rollers mounted on a base) actually interacted with his/her own object, however, when one of the objects was manipulated (by rotating a roller), both users' objects were affected. More recently, Motamedi presented "Keep in Touch," a fabric touchscreen interface combining visual and tactile sensations in order to provide a kind of physical intimacy between couples in long-distance relationships. In particular, each of the people using this device was presented with a blurred digital projection of his/her partner. Touching their partner's body brought their image into focus thus revealing their features. Unfortunately, a well-controlled experiment designed to determine whether or not such devices do indeed provide an effective means of interpersonal, multisensory, long-distance communication has yet to be conducted.

Another rather promising device that is probably worth mentioning here is *Time* magazine's best invention of 2006, the "Hug Shirt" (<<http://www.cutecircuit.com/now/projects/wearables/fr-hugs/>> downloaded on June 21, 2011). This device, which can best be described as a "wearable interface," according to the producers, allows a person to feel a hug from another user via a mobile network connection. There are a number of sensors embedded in each Hug Shirt that can detect the strength of the touch, the skin warmth, and the sender's heart rate. The shirt also contains

actuators that are apparently capable of recreating the sensation of touch, warmth, and emotion for the receiver. This device, which, from the outside, looks exactly like any other t-shirt, has the advantage of being portable, and is easily connectable (indeed it uses a Bluetooth communication system linked to a Java-enabled mobile phone). Unfortunately, 6 years later, from the website of its inventors it is not even clear if the Hug Shirt has ever hit the market (being still classified among the “special projects” section of the company’s webpage; see <<http://www.cutecircuit.com/category/special-projects/>> downloaded on October 2, 2012).

Despite of the apparent lack of success of the hug T-shirt, the same (or similar) concept has recently been re-introduced by a different research group, the MIT Media Lab’s Tangible Media Group, under the name of “Like-A-Hug” (see <<http://www.guardian.co.uk/culture/2012/oct/09/like-a-hug-facebook-vest-friends>> downloaded on October 8, 2012). This device has been developed as a sort of interface for social media, such as Facebook (<<http://www.facebook.com/>> downloaded on November 9, 2012) and it consists of a vest, looking like a black winter jacket, that can inflate like a lifejacket when friends on social media “like” a photo, video, or status update on the wearer’s Facebook wall. The developers of this project have suggested that such a device might allow us to “feel the warmth, encouragement, support, or love that we feel when we receive hugs.” It is, however, unclear how an inflating vest might be actually be perceived by the users as an actual “hug.” However, only the future will tell if this project is going to hit the marketplace at some point.

While few of these devices have been tested so far, the results of pilot studies have revealed positive feedback from the potential users (even if the limitations of subjective report should be considered; see our earlier critique to this approach). Other devices have stopped at a more conceptual level of development. For example, DiSalvo et al. (2003) and Gemperle et al. (2003) envisioned the “Hug,” a set of devices that can be connected to each other over a mobile phone network. The authors suggested that people might use this system in order to allow asymmetrical bidirectional physical interactions between individuals. Specifically, a person can stroke or squeeze his or her device, resulting in vibrations and temperature changes in the other person’s device. No updates have been seen on this project since then, perhaps suggesting that the transition from the concept to the actual realization and commercialization of this idea, turned out to be far more complex than expected.

In another “to-be-developed” project, Mueller et al. (2005) hoped to provide the receiver with a sensation that maximally resembles an actual hug by means of an inflatable vest and a koala-bear-like input device. Note, however, once again, that since the project was first reported in 2005 no major updates have been provided, leading to the suggestion that no major results have been achieved by the researchers working on this idea (see the project website: <http://floydmueller.com/portfolio/hug_over_a_distance.htm> downloaded on October 2, 2012).

The studies discussed thus far in this section highlight the growing importance (over the last decade or so) of trying to create devices which allow long-distance tactile interpersonal communications between people. To us at least, it seems that in order for these systems to achieve commercial success, further testing will be needed in order to address both the cognitive and affective aspects (and limitations) of human tactile information processing. We also believe that it is only through the interchange between different disciplines (such as anthropology, neuroscience, psychology, social sciences, ergonomics, and engineering) that people will, in the future, be able to enhance communication by means of tactile, as well as visual and auditory (and perhaps also olfactory) sensations, when they happen to be in different places. So far, it would appear that the number of people who actually desire the kind of tactile experience that can be delivered by the actual technology (outside of the sex industry, that is; see section 9.8) is very low.

One of the problems with many of the studies reported thus far in this section is that the majority of the devices that have been developed to date suffer from a lack of robust empirical testing. That is, facilitated by the availability of new technologies and higher computational power, new devices are quickly developed and built but tend not to be put through any kind of rigorous empirical testing. As seen already, in most of the studies reported in this section, the researchers involved have typically only reported the qualitative judgments of a small number of participants regarding a particular device (e.g., addressing questions such as whether the user can see themselves actively using such a device in the near future, if they think it could provide an useful means of communication, or sometimes just their general impression regarding the device). The critical question to answer here is: Do these devices lead to the same (or at least somehow similar) behavioral responses, psychophysiological consequences, and patterns of neural activation than could be obtained in a real interpersonal tactile interaction?³ In fact, it is worth noting here that most of the systems reviewed in this section were perhaps not actually designed to replicate or simulate real physical contact, but with the aims to reproduce the effects of touch on our social interactions and physical well-being (see Haans & IJsselsteijn, 2006, for further discussion of this point).

Moreover, as pointed out earlier in this chapter, we believe that technological advances (involving human operators) always need to depend on the advances in our knowledge regarding the functioning of the human cognitive system, and more specifically, regarding the mechanism of tactile and haptic perception (see also Miodownik, 2005). Without a synergy between these different fields of research, it would seem unlikely that any serious progress toward the goal of adding tactile sensations to long-distance or virtual communication will be possible (as it was the case in the 1970s for tactile communication devices; see section 9.6).

9.8 Teledildonics and the future of sex

As we will see in Chapter 13, tactile sensations play a major role in governing our sexual activities. It is not surprising, then, that over the last few years, a great deal of interest in the study of this sense has been exhibited by those brands that are related in some way to the adult entertainment market, everyone from condom makers through to the developers of videogames. Even the multi-billion dollar porn and adult sexual entertainment industry has, in recent years, turned its attention to the previously neglected sense of touch (including pain) and olfaction (see Behar, 2009; see also Zhou & Chen, 2008, for the report that the presentation of male sexual sweat collected from the armpits, obtained when the donors were watching pornography, activated areas of the orbitofrontal cortex in female participants). In fact, although one of the major thrusts of the adult entertainment industry has always been to develop and sell products that are capable of stimulating and feeding people's sexual desires and emotions, in the past, this has mainly occurred by exploiting the senses of vision and, to a lesser extent, audition. However, an important exception should be mentioned here. In particular, the development of instruments capable of automatically stimulating the genitals, such as dildos, had a very early beginning in the history of household electrical appliances, if one considers that the very first vibrator for home-use was patented in 1902 by Hamilton Beach of Racine, USA. Note that more costly stimulating machines were already available to doctors for the treatment of "hysteria" about 30

³ See Haans, de Nood, and IJsselsteijn (2007), for an example of a negative answer to this question, and Haans, IJsselsteijn, Graus, and Salminen (2008), for evidence that the "Midas touch effect" does not occur when people are touched by a haptic device designed to simulate mediated social touch.

years earlier. This piece of equipment was the fifth electrical appliance to be introduced into people's homes, just after the sewing machine and well before the electric iron (e.g., Maines, 1999; Thorpe, 2010).

The term "teledildonics" was originally coined by the artist Stelarc in the mid-1990s. It refers to any remote sexual stimulation that is controlled through some sort of electronic channel of communication, though it usually refers to Internet/computer-controlled sexual activity. Commercial teledildonics products came to market in the late 1990s, with devices like SafeSexPlus and Symphony allowing users to control the vibration speed of sex toys over the Internet. More recently, other companies such as Sinulate Entertainment LLC and Highjoy have also started to market toys with Internet-enabled speed and rotation controls. For example, the "Sinulator" device by Sinulate Entertainment includes a transmitter, a vibrator, and a receiver all controlled by a software interface. A standard vibrator for men, "The Fleshlight," can also be used as a transmitter. It measures the speed and force of each movement of the male member and communicates the metrics to the software, which in turn, translates them into sequences of vibrations and pulses at the other end. That is, two persons using this device might engage in simulated sexual intercourse despite the fact that they happen to be separated by a great distance. Other uses of teledildonics technology are related to the adult videogames industry. For example, *Virtually Jenna* developed by XStream3D Multimedia, is an online game in which the player can have sex with a realistic cartoon depicting the porn star Jenna Jameson. Hardware devices following the action to genitalia can also be linked to the game. In this case teledildonics are adopted in human to computer-generated simulations.

Over the last few years, the popularity of virtual worlds such as *Second Life* by Linden Lab or the fantasy game *World of Warcraft* by Blizzard Entertainment has rapidly increased (see Wagner, 2008). Not surprisingly, sexual behavior has also spread within these simulations and avatar genitals, as well as sex animations, have become popular features among users of *Second Life* (Wagner, 2008; see also Bland, 2008). Note, however, that all of these sexual features do not involve actual tactile stimulation, but are only visual counterparts of them. That is, the avatars within these virtual worlds can touch each other and engage in sexual relationships but the user does not experience anything more than what they can see. Perhaps unsurprisingly, a number of attempts have been made to add teledildonics technologies to these interactions. For example, a few years ago, robotics engineer Kyle Machulis presented the first open-source interface for controlling sex toys from within the virtual world, the SeXBox (see Machulis, 2006).

Even though the use of teledildonics technologies is not all that widespread in virtual worlds it is likely that it might be in the future of virtual entertainment (provided that a number of technical limitations are successfully addressed). One might even expect that not only will human-to-human mediated sexual interactions be possible, but also human-to-computer generated partners may become a viable reality (see also <http://www.bbc.co.uk/news/business-23637225> downloaded the 1st of September 2013, for the possibility to sexually interact with robots in the future). In that case, it would be relevant not only to reproduce accurate tactile sensations in the human user, but also to select and simulate those responses that tactile stimulation produces in a computer-generated avatar. Without taking into account these considerations, the realism of the simulation will be unlikely to be sufficient to elicit a robust sense of presence in the user. For example, the artist Tomoko Hayashi (<<http://www.tomoko-hayashi.com/home.html>> downloaded on October 20, 2012), has developed a computer vision and projection system that allows users to write or draw on their own bodies while lying in bed. The drawings made by one partner are then transmitted to the body of the remote partner. As such this device should allow for more intimate forms of communication among partners. Note, however, that such a device is unlikely to generate the same reactions produces by real intimate stimulations of the body.

Teledildonics technologies are not only relevant to the porn industry though. Their introduction may also come to help in those situations in which partners are separate by long distances. For example, Company manager Scott Rinaldo, appearing in 2012 at a Consumer Electronics Show held in Las Vegas and sponsored by porn firm Pink Visual, said that he is working on distributing an Internet-connected sex toy that can let couples thousands of miles apart to “get intimate.” That is, the award-winning object developed by Rinaldo’s company and known by the evocative, if not a little pretentious, name of “RealTouch,” warms-up, lubes-up, pulses, and grips any item stuck into it based on data from an Internet connection. On the other end of the connection, a performer hand operates a sensor-covered rod to run the motors in the RealTouch. Rinaldo’s main idea was to distribute this teledildonic device to those serving in the U.S. military (e.g., in Afghanistan). No claims from the army have been released so far, perhaps suggesting that the use of this device is not yet under serious consideration within such an environment. Note also, that one of the factors that might jeopardize the possibility of using such devices in this kind of context, might be the limited bandwidth available. That is, even if only a smaller fraction of the 80,000 soldiers deployed in Afghanistan were to use this device, one can only imagine the amount of bandwidth necessary to support the transmission of such an amount of (sexually oriented) data simultaneously (even without considering the connectivity limitations likely affecting a war zone).

Despite the various attempts that have been made by robotic engineering companies and experts to move toward the addition of sexual interfaces to virtual or mediated interactions, the actual popularity of these devices among sexually active users is still a matter of concern among developers. Why is that, you might ask? Certainly there are a number of reasons that might help to explain the limited use of teledildonics in virtual simulations or mediated relationships. Some of the reasons are related to the financial costs involved, but these are certainly the less relevant, considering that since its birth the porn industry has witnessed a seemingly endless growth in its revenues (see <<http://www.forbes.com/2001/05/25/0524porn.html>> downloaded on October 17, 2012). Technological problems including the limitation of bandwidth are certainly important factors. Just how many people, do you think, would be willing to tolerate the system crashes while engaged in intimate relationships? However one of the more important reasons behind its limited success so far is well summarized by the words of Kevin Alderman, developer of an alternative virtual world called *Eros-3D* devoted exclusively to sexual interactions: “Nothing will ever replace the tactile sensation of warm flesh” (Bland, 2008). That is, the realism that can be obtained by using such interfaces at the moment is still far from being exhaustive, especially when the sense of touch is considered. This result is likely related to the fact that designers in the field often fail to reproduce the complete blend of sensations (thermal, tactile, olfactory, visual, etc.) that contribute to our sexual relationships. That said, one should also acknowledge the fact that a lack of scientific knowledge regarding what actually needs to be reproduced (and how) in order to make intimate virtual interactions more pleasurable still affects this field of research.

One of the main problems here might be that people respond differently to interpersonal and mechanical/mediated touch (e.g., Haans, de Nood, & IJsselsteijn, 2007; Haans & IJsselsteijn, 2006; see also Giannopoulos, Wang, Peer, Buss, & Slater, 2011, for a comparison between people’s responses to real and virtual handshakes). For example, when attempts have been made to reproduce certain effects of social touch, such as the Midas touch effect, by means of mediated or virtual interaction, the results have not been very promising (see Haans, IJsselsteijn, Graus, & Salminen, 2008; see also Chapter 7). Therefore, one of the main challenges for researchers in this field should be to try and trick people’s minds into believing that the interactions that they experience are determined by social rather than mechanical stimulation. We believe that the insights provided by the increasing number of studies devoted to exploring the neurocognitive bases of

our sexual (and, more generally, our social) behavior and the role of tactile and multisensory stimulation in it, is likely to offer further bases for the development of more successful sexual interfaces in the years to come. For example, one might envision that delivering the right pattern of tactile stimulation to different parts of the body as well as providing the correct blend of visual, acoustic, olfactory, and even hormonal (and perhaps also pheromonal) signals within a simulation, might result in a pattern of neural activation that resemble that obtained by the actual sexual situation (and thus resulting into the same perceptions and pleasures).

9.9 Conclusions

In this chapter, we have seen that tactile technologies, from touch screens to robotic surgery are becoming an increasingly important aspect of our life. In particular, it is now clear that tactile devices are being incorporated into a whole range of machines and appliances varying in terms of their complexity and their functionality (such as mobile phones and tablet PCs, as well as robots and artificial prosthesis). There have been attempts to incorporate into these devices perceptual as well as social aspects of touch, with mixed results. In particular, from the review of the literature outlined here, it would seem that interpersonal tactile contacts are the most difficult to reproduce. This might be related to the lack of similarity between the sensations that can be obtained in a human-to-human interaction and those that are used to simulate (or more simply to substitute for) these contacts. That is, a buzz coming from a computer mouse cannot exactly be considered as being similar to a handshake, even when delivered by a human agent. Moreover, even if touch is certainly an important aspect of our social interactions (and especially of the more sexual aspects of them), it is the blend of sensory attributes coming from different sensory modalities that contribute most to classifying a given experience as social.

Over the course of this chapter, we have seen that there are certainly great advantages to be had in reproducing tactile sensations in a number of different domains. For example, the realism of gaming, or of virtual simulations, can certainly benefit from the possibility of enriching the scenarios presented by means of tactile (and perhaps occasionally even noxious) stimuli. However, the present chapter has also highlighted that some technical challenges (such as the possibility of simultaneously reproducing both the microgeometric and macrogeometric surface properties of objects, as well as their thermal and proprioceptive sensations) need to be tackled before people might really appreciate these potential benefits. Other limitations (perhaps the most profound) more than technological appear to be related to our scientific knowledge regarding how our brain processes tactile information and integrates it with information from the other senses. Given its potentialities, and despite the limitations that still affect this area of research, we expect that the trend toward increasingly using tactile stimulation in modern technology will continue in the coming years (see Chapter 15, for possible future directions). However, we also believe that the success of this area will be largely determined by the development of a more collaborative approach among companies, neurocognitive scientists, engineers, and designers working on different aspects of our tactile interactions with the external world.

Tactile and multisensory warning signals

10.1 Introduction

Many exciting developments have taken place over the course of the last 10–20 years in the area of tactile and multisensory interface design. In fact, in contrast to the rather disappointing evolution of many tactile/haptic technology devices, reviewed in Chapter 9, delivering warning signals for drivers is one area where genuine progress in the applied domain has been taking place. For example, tactile signals are increasingly being used to awaken sleepy drivers, to capture the attention of distracted drivers, and even to present more complex information to drivers who may be otherwise visually overloaded. In this chapter, we will highlight the key potential costs and benefits associated with the use of tactile and multisensory information displays. The focus in this chapter will therefore be on the practical implementation of a variety of different warning signals for use in the setting of commercial road vehicles. The extant research now suggests that multisensory displays based on the latest findings from the field of cognitive neuroscience are capable of capturing a driver's attention significantly more effectively than their unimodal (i.e., tactile, visual, or auditory) counterparts (see Spence, 2010a, b, 2012a). Various research findings also suggest that multisensory displays can be used in order to transmit information to drivers more efficiently, as well as, on occasion, to reduce their workload. In the final part of this chapter, we highlight a number of the most important research questions currently awaiting further study in this very dynamic area of research.¹

For more than half a century now, researchers have been interested in the utilization of tactile (or haptic) displays to assist interface operators working in visually cluttered or overloaded environments (e.g., Hawkes, 1960; Tang et al., 2005; see Chapter 9), not to mention in a variety of other adverse operating conditions (Carlander et al., 2007; Chen & Terrence, 2008; Oskarsson et al., 2012; Rupert, 2000; Terrence et al., 2005; Van Erp & Van Veen, 2006; Van Erp et al., 2007). By now, numerous studies have documented the potential benefits associated with the presentation of tactile stimuli for pilots and other interface operators working under more or less extreme operating conditions (e.g., Chen & Terrence, 2008; Ferris & Sarter, 2008; Gallace et al., 2007a;

¹ In much of the literature on ergonomics and human interface design, the term “haptic” has been used to describe the stimulation of the participants’ skin/body (e.g., see Fitch et al., 2007, 2011). However, in the cognitive psychology/psychophysics literature, as in the previous chapters of this volume, this term has a very specific meaning, one that is restricted to describing those tactile stimuli that impinge on the skin, and which are perceived by means of a person actively palpating an object or surface, such as when actively exploring an object held in the hand. By contrast, the term “tactile” is used to describe those stimuli that are delivered passively to the skin surface (see Chapter 1). Given that the majority of the tactile displays and warning signals discussed here involve such passive stimulation of the driver, we will use the term “tactile” in this chapter.

Sklar & Sarter, 1999). However, regulatory restrictions have meant that little progress has been made in terms of implementing such tactile displays in, for example, commercial planes beyond the traditional stick shaker (Gast, 1998). By contrast, while research interest in the incorporation of tactile warning signals/displays in commercial vehicles has only really emerged relatively recently (e.g., McGehee & Raby, 2002; Sato et al., 1998; Suzuki & Jansson, 2003; Tijerina et al., 2000), a number of commercial vibrotactile safety systems have already appeared in the marketplace (albeit, with the exception of the new KIA vibration system, mostly as optional extras, rather than standard features). For example, the lane departure warning systems available in certain models of Citroën and BMW cars (see “Lane departure warnings,” 2005; Smith, 2004) or the Advanced Vehicle Safety Management (AVSM) implemented in 2012 in some KIA models (<<http://thekoreancarblog.com/2012/07/kia-named-quoris-k9-flagship-sedan-export-markets-wvideos>>; downloaded on October 17, 2012). What is more, according to the Denso Corporation, one of the world’s largest manufacturers of car parts, all new cars will be fitted with some sort of tactile stimulation device as standard by the year 2020 (see Ho & Spence, 2008).

This chapter opens by looking at what has been learnt in terms of the optimal design of tactile and multisensory (i.e., audiotactile or visuotactile) warning signals and informational displays for car drivers. Next, some of the most important costs and benefits associated with the use of tactile displays in this situation are highlighted. We then go on to look at a number of specific applications for such displays, namely awakening drowsy drivers, capturing the attention of distracted drivers, and finally, reducing the workload of drivers who may be overloaded. The research described in this chapter will also be relevant to considering the limitations associated with the possible use of more advanced tactile information displays in vehicles. Finally, we conclude the chapter by outlining a number of the most pressing questions that will need to be addressed by future research on the design of tactile and multisensory warning signals.

10.2 Assessing the costs and benefits of tactile warning signals and information displays

It has often been claimed that drivers suffer from visual overload (see Spence & Ho, 2008b, for a review). Indeed, some researchers have suggested that as much as 85–90% of the information that a driver needs/receives is visual (Senders, Kristofferson, Levison, Dietrich, & Ward, 1967; though see also Sivak, 1996). As such, many of those working in the field of interface design have, for a number of years now, been actively thinking about the possible use of a variety of non-visual displays in order not to increase a driver’s *visual* workload still further. While it is certainly true that the majority of this research has focused on the development of effective in-vehicle auditory signals and displays (see Edworthy & Hellier, 2006; Ho & Spence, 2005; McKeown & Isherwood, 2007), a growing number of researchers have also started to consider the possibilities associated with the use of tactile warning signals and even more complex tactile information displays (e.g., Ho & Spence, 2008). As was noted in the opening chapter of this volume, the skin represents by far the largest of our senses (see Montagu, 1971). At present, though, the sense of touch seems to be relatively little used by the average driver. However, as soon as one starts to consider the implementation of non-visual warning signals in vehicles, it soon becomes clear that tactile warning signals have a number of potential advantages relative to their more widely studied auditory counterparts.

Stimulating the sense of touch would appear to offer a number of potential benefits in terms of capitalizing on this currently underutilized sense in order to deliver warning signals and possibly other kinds of information without necessarily overloading a driver’s limited attentional resources

(see Hancock et al., 2007; McGehee & Raby, 2002; Sarter, 2007; Wickens, 2002; though see also Spence & Driver, 1997). Following on from the observation that a great deal of tactile processing occurs implicitly (see Chapter 5), it is often claimed that tactile stimuli may be automatically attention-capturing (Sarter, 2000), and hence that a driver would not need to “look out” for tactile warning signals in order for them to automatically capture their attention (McGehee & Raby, 2002). However, the available evidence from the psychophysics laboratory certainly appears to argue that tactile stimuli don’t always capture our attention automatically, at least not when our concentration happens to be engaged elsewhere (e.g., on monitoring a rapidly presented serial visual presentation stream; see Santangelo & Spence, 2007b; see Chapter 6).

One of the most important advantages offered by stimulating the sense of touch is that our perception of tactile stimuli is thought to be relatively unaffected by the level of auditory background noise (Auvray et al., 2008; Brown et al., 1965; though see also Gescheider & Niblette, 1967). This contrasts with the case of audition, where trying to ensure the audibility of warning signals and displays over and above any background road noise, or even the sound of the car stereo can represent a very real problem (Ho & Spence, 2008; Ramsey & Simmons, 1993; Slawinski & McNeil, 2002). Of course, the whole-body vibration (which can be considered as a form of tactile noise) that is experienced when we drive on an uneven road surface is likely to have a more detrimental effect on the processing of tactile warning signals than on the processing of auditory signals. On the other hand, though, there is always a danger that certain tactile cues, especially those delivered to the back of the driver’s seat, may simply be rendered ineffective to a driver who happens to be wearing particularly thick clothing (e.g., when driving in the middle of winter; see Lee et al., 1998). That said, a number of studies have now demonstrated that many contemporary vibrotactile stimulators are powerful enough to operate effectively through a variety of everyday clothing (Ho et al., 2006a, 2007a; McGehee & Raby, 2002). Researchers have even tried delivering tactile/haptic signals through the soles of a driver’s shoes (Janssen & Nilsson, 1993). Of course, one needs to determine how pleasant/unpleasant drivers find such warning signals (e.g., see Fitch et al., 2011), and whether their alerting capacity in one task might not actually be distracting when it comes to the driver performing another task.

It would, however, seem that one of the most important advantages offered by tactile displays is that they allow for the delivery of signals that are targeted specifically at the driver. In contrast to the more commonly used auditory warning signals, passengers need not be made aware of (and hence will likely not be distracted by) any tactile warning signals that happen to be delivered to the driver’s body. Furthermore, within the confined space of the car interior, tactile warning signals may well prove themselves easier to localize than many auditory warning signals (e.g., see Fitch et al., 2007; Tan & Lerner, 1996; though see also Ho et al., 2006b). Thus tactile cues would therefore appear to offer a particularly effective means of presenting directional signals to drivers (see also de Vries et al., 2009; Jones et al., 2008). And while many researchers have argued that tactile cues are “intuitive,” it should be borne in mind that a precise definition of this term remains elusive (Ho et al., 2007b). Roughly speaking, the majority of researchers appear to have taken the term to mean that an intuitive warning signal is one that is capable of triggering a response from the driver that occurs without a necessary act of response selection or without requiring access to semantic information regarding the meaning of the signal itself. Nevertheless, the notion that such infrequent warning signals need to have an easily recognizable meaning, or else automatically capture a distracted driver’s spatial attention (see Spence & Ho, 2008c), appears to be widely accepted by the majority of researchers working in the field (Suzuki & Jansson, 2003; see also Baldwin & Runkle, 1967, for an early discussion concerning the need for easily noticeable and recognizable warning signals).

One concrete example that serves to highlight the potential benefit of using tactile warning signals comes from a study reported by Janssen and Nilsson (1993). They demonstrated that presenting a counterforce (consisting of an increase of 25 Newtons) on the gas pedal whenever a driver was too close to the vehicle in front resulted in safer driving behavior (at least in the driving simulator) than when the same warning information was presented either visually or auditorily instead.

It can be argued, then, that tactile warning signals offer a number of potential benefits over other kinds of non-visual (essentially auditory) warning signals for drivers. That said, it is important to note that there are also some important constraints limiting the successful incorporation of tactile displays, particularly when it comes to their use in the context of commercial vehicles. First and foremost, the majority of car manufacturers are convinced that new tactile displays will need to be easy to use. As a consequence, they should not require extensive (or perhaps even any) training in order for a driver to be able to use the system efficiently (see Suzuki & Janssen, 2003)—this, then is part of the reason why the idea of intuitive warning signals is so appealing. Note here that this constraint does not apply to the majority of other domains where tactile interfaces/displays are currently being introduced, such as military (Chen & Terrence, 2008; Jones et al., 2006), aviation (Ngo, Pierce, & Spence, 2012; Rupert, 2000; Sklar & Sarter, 1999), surgery (see the previous chapter), and/or space applications (Terrence et al., 2005; Van Erp & Van Veen, 2006), where extensive training with a new display technology isn't considered problematic. That is, in the development of warning signals or interface design, it often turns out that what works properly in a highly specialized working environment does not necessarily provide the optimal solution for the average person driving the family car on the school run.

Fortunately, most of us will be involved in a car accident only very rarely over the course of our lifetimes on the road (even if road accidents are one of the leading causes of mortality for the healthy adult population). This means that tactile warning signals are likely to be presented fairly infrequently, especially if one wants to avoid what is known as the “cry wolf” phenomenon (see Bliss & Acton, 2003; Breznitz, 1983; Dixon et al., 2007). This occurs when an interface operator starts to ignore (or worse still, even to disconnect/switch off) a warning system if it starts to deliver too many false alarms. The fact that tactile and/or multisensory warning signals should only be presented very rarely means that it is important that their meaning be immediately apparent to the driver, even if they haven't experienced such a warning signal for a long time (see Spence & Ho, 2008c, on this point). The critical question here then becomes one of whether, beyond the presentation of directional cues, it is possible to present tactile messages (or icons) that are more-or-less instantly comprehensible, in a manner similar to the “auditory icons” favored by those working on the design of auditory alerts (e.g., Bussemakers & de Haan, 2000; Gaver, 1986; McKeown & Isherwood, 2007).

Auditory icons are those instantly recognizable sounds, such as the sound of a car horn, or the sound of paper being scrunched up when you place a file in the wastebasket on a computer desktop. To date, though, there hasn't been all that much work on this topic (Brewster & Brown, 2004; Brown & Kaaresoja, 2006; Brown et al., 2006; Chan et al., 2005; Ferris & Sarter, 2010; Hoggan & Brewster, 2007; Luk et al., 2006; MacLean & Enriquez, 2003; Tang et al., 2005). Certainly, it is much harder to think of what tactile icons (what some have labeled “tactons”) might consist of, than it is to generate meaningful auditory icons (though see MacLean, 2008). However, one interesting, but as yet relatively unexplored, possibility here involves the development of tactile displays that capture the everyday affordances of stimuli. So, for example, one idea that is currently being tested in Oxford involves the incorporation of some sort of expanding tactile pattern to mimic what happens when a visual stimulus looms toward us, or the increase in intensity that you hear when a sound-emitting stimulus approaches rapidly (see Gray, 2011; Ho, Spence, &

Gray, 2013). Certainly, visual and auditory looming signals seem to capture the attention of participants in laboratory studies more effectively than many other kinds of stimuli (Hall & Moore, 2003; Terry et al., 2008). One might therefore wonder whether a graded expanding tactile display presented to the front of a driver's torso would work well as an intuitive tactile collision avoidance warning signal (cf. Lee et al., 2004; Suzuki & Janssen, 2003). Note, however, that while an auditory looming signal is naturally mapped into a possible danger when the motion is directed toward one's body, its tactile equivalent might not (in the majority of the cases we are used to feeling tactile stimuli when they have already reached our body rather than when they are approaching it).

Finally, the majority of car manufacturers are firmly of the opinion that it will prove very difficult, if not impossible, to convince most drivers to attach any kind of tactile device to their bodies whenever they want to drive their car (just remember how difficult it was, and in some cases still is, to convince people to wear seat belts in cars or even helmets for motorbike drivers). This means that tactile vests (cf. Jones et al., 2006) are out. Instead, researchers would be best advised to focus their attention on the delivery of tactile stimuli via those surfaces of the car that the driver is already in contact with. In practice, then, this means that tactile stimuli can only realistically be delivered via the driver's seat or seatbelt (Ho et al., 2006a, 2007a; Lee et al., 2004), via the steering wheel (e.g., Sato et al., 1998; Suzuki & Jansson, 2003), via the footpedals (de Rosario et al., 2010; Janssen & Nilsson, 1993), or via tactile feedback from any in-car device (or information-system) that incorporates some kind of touch technology (see Lee & Spence, 2008; Lee et al., 2009). For those who know/remember it, one can think of the troubled Immersion/BMW iDrive (Day, 2004).

Given the various costs and benefits associated with the use of tactile displays in cars, the next question to ask here is what progress has so been made so far by researchers in terms of the successful design of tactile displays for drivers? There are currently a number of potential uses for tactile displays in vehicular settings: First, to arouse or awaken possibly drowsy drivers (see Smith, 2004); second, to alert drivers to impending danger and orient their spatial attention using directional tactile (or multisensory) cues (see Ho et al., 2005, 2006a, 2007a; Ho & Spence, 2009; Scott & Gray, 2008); and third, to reduce driver workload when interacting with in-vehicle devices (such as the Satellite Navigation System, or SatNav) by providing tactile (and/or multisensory) feedback concerning a driver's action (Asif, Boll, & Heuten, 2012; Hogema et al., 2009; Lee et al., 2009; Lee & Spence, 2008, 2009 Van Erp & Van Veen, 2004) (Figure 10.1). In the sections that follow, we will look in turn at the evidence concerning each of these potential applications.

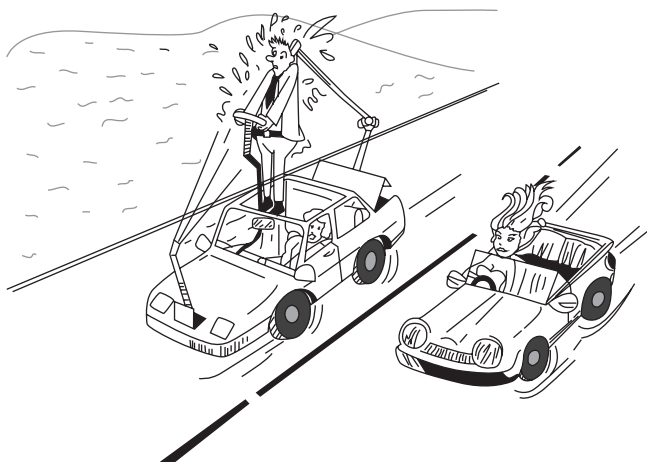


Fig. 10.1 "Stop blinking. The car will think you're nodding off."

10.3 Tactile alerting signals: Awakening the drowsy driver

One of the most successful commercial implementations of tactile stimulation in vehicles to date has resulted from their use in warning drivers whenever they cross a lane boundary too slowly—often a clue that a driver may be on the point of falling asleep. In fact, it has been suggested that up to a third of all vehicular accidents may result from drivers falling asleep at the wheel, thus making drowsiness one of the leading causes of vehicular accidents (see Sagberg, 1999). In 2004, Citroën brought out their Lane Departure Warning System (LDWS) as an optional extra in several of their models (see “Lane Departure warnings,” 2005; Smith, 2004). This device was designed to alert potentially drowsy drivers by vibrating one of their buttocks should they happen to cross a lane boundary too slowly. The vibrotactile warnings implemented in these LDWSs were also designed to be spatially informative: That is, if the car veered slowly to the right, then the right side of the base of the driver’s seat would vibrate, and vice versa whenever the car veered too slowly off to the left. Note that this kind of tactile feedback can be thought of as mimicking the vibrations that one feels as a driver when one’s car makes contact with the rumble strips that one sometimes finds at the edge-of-carriageway (see also McGehee & Raby, 2002)—though, of course, those are not likely to be as spatially specific. It is also worth bearing in mind here that these tactile warning signals are normally only presented when the driver fails to turn on the indicator while traveling at speeds in excess of 50 mph.

The results of a driving simulator study conducted by Suzuki and Jansson (2003) revealed that the vibration of the steering wheel can also be used to warn drivers about lane-departure situations. Vibrating the steering wheel, or delivering a pulse-like steering torque warning signal to the steering wheel (see also Sato et al., 1998), were significantly more effective than presenting an auditory tonal alert, either monaural or stereo, under conditions where the drivers had not been informed about the meaning of the warning signals in advance. In fact, the experienced drivers tested in this particular study reacted more than half a second faster following the presentation of either the vibrating or torque warning signals than following either one of the auditory alerts when those warnings were not expected (to put these results into some kind of perspective, it should be noted here that such a reduction in braking latencies has been estimated to equate to a 60% reduction in front-to-rear-end collisions; Suetomi & Kido, 1997). By contrast, response latencies were pretty much identical once the participants in this study had been made aware of the meaning of the upcoming warning signals. That said, the vibrating steering wheel also resulted in the smallest lateral deviation of the driven vehicle, leading Suzuki and Janssen to argue that it represented a particularly effective form of tactile LDWS. They suggested that their drivers may have “intuitively” understood the vibration of the steering wheel as signifying that the driven vehicle was deviating from the allocated lane. However, it should also be noted here that several of the participants actually turned in the wrong direction following the unexpected presentation of torque on the steering wheel (see also Beruscha et al., 2010).

It would certainly be interesting in future research to compare the effectiveness of the directional seat vibrations currently incorporated in a number of commercial vehicles with the vibration of the steering wheel as warning signals. It would also be worthwhile investigating whether the combined presentation of these tactile cues at the same time would lead to an enhancement of driver performance over and above that delivered by the best of the warning signals when presented individually (cf. Fitch et al., 2011; Santangelo et al., 2008; Spence, 2010b). Finally, it would also be sensible to compare these tactile warning signals with the visual and/or auditory lane departure warning signals currently in use in a number of vehicles (see Smith, 2004).

10.4 Tactile warning signals: Capturing the attention of the distracted driver

A second area that has attracted a great deal of research interest in recent years relates to the development of intelligent collision warning systems. One of the most intensively studied approaches of this type tries to help drivers avoid front-to-rear-end (FTRE) collisions (e.g., Ho et al., 2005, 2006a; Lee et al., 2004; Tijerina et al., 2000). FTRE collisions are one of the most common causes of vehicular accidents (see Evans, 1991), and their incidence is particularly high amongst distracted drivers, such as those drivers who use their mobile phone while at the wheel when driving (see Ho & Spence, 2008; Moehebbi, Gray, & Tan, 2009; Sagberg, 2001).

By now, a number of studies have demonstrated that spatial tactile warning signals can provide an effective means of warning drivers about a potential impending accident, such as a FTRE collision (see Ho & Spence, 2008, for a review). For example, the participants in one such laboratory-based study watched a video showing a car driving on the road ahead of them, and another car behind them, seen via the rear-view mirror (Ho et al., 2005). The participants had to accelerate whenever the trailing car suddenly accelerated, and to depress the brake pedal whenever the lead car braked suddenly. Spatially predictive vibrotactile warning signals, delivered from a belt attached just above the participant's waist, were presented from the same direction as these "critical" driving events on a majority (80%) of the trials. In other words, the participants felt a vibration on their stomach if the lead car suddenly decelerated, while they felt a vibration on their back if the trailing car accelerated. The vibrotactile warning signals were presented from the invalid (i.e., opposite) direction to the potential collision on the remainder of the trials (see Chapter 6 for a review of the literature on the spatial orienting of tactile attention). The results of this study revealed that the participants responded significantly faster, and somewhat more accurately (that is, they made fewer inappropriate braking or acceleration responses) following the presentation of a directionally appropriate tactile warning signal than following the presentation of a spatially invalid warning signal. The mean reduction in driver responses reported in this experiment was in excess of 60 ms.

Interestingly, the magnitude of these vibrotactile spatial cuing effects were only slightly (but not significantly) reduced when the tactile cues were made spatially non-predictive with respect to the location of the critical driving event (i.e., under conditions where the warning signal was just as likely to be presented from the participant's stomach as from their back, regardless of where the critical event happened to be unfolding on the roadway; Ho et al., 2005). This latter result supports the view that tactile warning signals capture attention exogenously (and not only endogenously; see Chapter 6). That is, participants' attention was captured by the stimulus itself, rather than necessarily by the informative content of the warning signal. It should, however, also be noted that the spatially informative vibrotactile cues utilized in Ho et al.'s study, while giving rise to a significant improvement in both the speed and appropriateness of participants' braking responses, was not as effective as the spatially informative auditory icon (the sound of a car horn) presented in Ho and Spence's (2005) study (see also Ho et al., 2006b). In fact, across a number of studies, tactile spatial cues have now been found to be somewhat less effective than spatialized auditory icons, even with exactly the same experimental designs.

So why should it be that auditory warning signals are more effective than tactile signals in terms of speeding a driver's responses? While both the presentation of a car horn sound from in front of the driver, and the vibration of the front of the driver's waist carry useful information regarding the likely source of any danger on the roadway, only the sound of the car horn carries an "intuitive" semantic meaning. Hence, part of the answer here would seem to lie in the fact that the auditory icon can simply be understood more readily by people than can a sudden-onset tactile

signal (cf. MacLean, 2008; Tijerina, 2001). However, an equally important reason why the tactile cues may be somewhat less effective in this setting is that touch is a proximal sense (that is, we normally only experience touch when delivered to the body surface). As a consequence, it may well be that when presented by themselves, tactile warning signals are only capable of drawing a driver's attention to their peripersonal space (i.e., to the space around the driver's body in the car itself; Ho et al., 2006b). By contrast, audition and vision are distal senses, capable of informing us both about events that are close at hand, but also about events occurring much farther away (that is, ahead on the roadway; see also Previc, 1998). Auditory and visual signals may therefore simply have a greater capacity to direct a driver's attention to those regions of extrapersonal space that lie outside the interior of the car where critical driving events are likely to take place (see Ho & Spence, 2008; Ho et al., 2006b; cf. Previc, 2000). Indeed, the available research now suggests, perhaps unsurprisingly, that extrapersonal warning signals may be more efficient at directing a driver's attention to the extrapersonal space outside the vehicle than are unisensory tactile signals (see Ho & Spence, 2008).

Ho et al. (2006a) conducted another study in a high-fidelity driving simulator in which the participants had to try and keep a fixed distance from a lead vehicle that they were following around an urban road layout. The drivers were provided with an in-car visual display that informed them whether they were traveling at the right distance from the lead vehicle or not. This display, which the drivers had to monitor, was designed to mimic the attentional demands of a typical piece of in-car technology (or in-vehicle information system), such as, for example, a SatNav (see Ashley, 2001; Spence, 2012a). Periodically, the lead vehicle would brake, and the participants (drivers) had to do the same so as to avoid a potential FTRE collision. Ho et al. compared the speed of participants' braking responses on those trials in which no warning signal was presented, equivalent to the typical situation for drivers in the majority of cars on the road today, to that seen when a vibrotactile warning signal was presented at the exact same moment that the lead vehicle started to decelerate. Presenting tactile warning signals from the appropriate direction (on the participant's stomach) led to a significant 400 ms reduction in participants' braking responses.

One potential limitation, however, with regard to the practical implications of Ho et al.'s (2006a) research concerns the fact that the vibrotactile warning signals were presented as soon as the lead vehicle started to brake (what is more, the brake lights in the lead vehicle had also been disabled). Presumably, though, any actual in-car collision avoidance system would take a certain amount of time to detect such a braking event on the roadway and hence to determine whether or not a tactile warning signal ought to be presented (Brown et al., 2001; Ho & Spence, 2008). It will be an interesting challenge for future research to determine just how effective vibrotactile collision avoidance warning signals are when they are presented at varying delays after the onset of braking by a lead vehicle (see Hirst & Graham, 1997; Lee et al., 2006; Scott & Gray, 2008).²

To date, the majority of research on tactile FTRE collision warnings has considered the delivery of abrupt single-stage warning signals. However, simulator research conducted by Lee et al. (2004) has demonstrated that the use of *graded* (as opposed to abrupt) tactile warning signals may sometimes be preferable (see also Chapter 9, for a similar approach to interfaces used in the operating room). In particular, according to their research, drivers appear to trust graded tactile warning signals, where the intensity and frequency of the seat vibration increases as the warning level

² On the other hand, however, it could also be said at this point that a driver does not always need to brake immediately when the car in front does. Hence, such a delay might not practically represent such a significant problem.

became more severe, more than single-stage abrupt warnings. Graded warning signals were also rated as less annoying, not to mention being judged as more appropriate, than sudden-onset signals. Finally, the graded tactile warnings led to greater safety margins and to a lower incidence of inappropriate responses to nuisance warnings in this particular simulator study. Building on such findings, then, one possibility that is currently being investigated in the Crossmodal Research Laboratory in Oxford (together with Dr. Cristy Ho, and Dr. Rob Gray from the University of Birmingham) concerns the delivery of gradual-onset tactile warning signals modeled on the auditory looming signals presented by Gray (2011). Ho et al. are currently investigating whether a simple increase in tactile stimulus intensity over time will be sufficient for such warning signals, or whether instead they might be rendered more effective by the additional utilization of an expanding pattern on the driver's stomach (or possibly, back).

Thus far, the research that has been reviewed in this chapter has involved the presentation of unimodal tactile (or, on occasion, auditory or visual) warning signals. However, there is now a growing body of empirical evidence, from both laboratory experiments and driving simulator studies, to suggest that multisensory warning signals may offer a number of important advantages in terms of engaging a driver's attention over the best of the unisensory warning signals that have been documented to date (e.g., Spence, 2010b; see also Chapter 11).

For instance, Ho et al. (2007a) reported a driving simulator study in which they highlighted the potential benefit associated with the presentation of multisensory (over unisensory) warning signals. These researchers compared the effectiveness of the combined presentation of auditory and tactile warning signals presented simultaneously (the multisensory warning signal), and from the same direction, as compared to auditory warnings and tactile warnings when presented in isolation (i.e., unimodally). Ho and her colleagues assessed the effectiveness of these warning signals in speeding a driver's responses to potential FTRE collisions. Overall, the results suggested that the presentation of multisensory warning signals led to an improvement in a driver's braking responses of approximately 600 ms (see Spence & Ho, 2008a) relative to when no warning signal was presented (Figure 10.2). The best of the unimodal warning signals, namely the sound of the

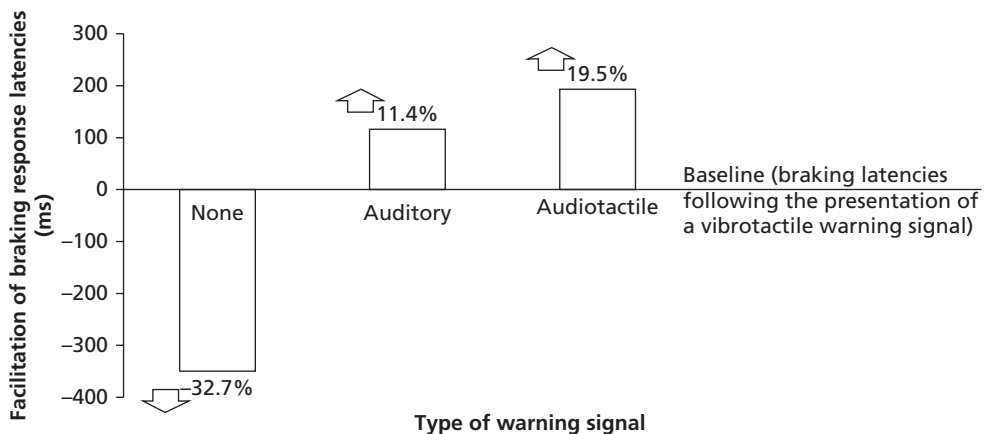


Fig. 10.2 Graph highlighting the potential benefits (in terms of the facilitation of braking latencies in a simulator-based driving task) associated with the use of combined audiotactile (i.e., multisensory) warning signals over unimodal auditory, unimodal tactile (baseline performance) or current no warning signal conditions (see Ho et al. 2007a, for details). Reproduced from Charles Spence, Cristy Ho, "Tactile and Multisensory Spatial Warning Signals for Drivers," *IEEE Transactions on Haptics*, vol. 1, no. 2, pp. 121–129, © 2008, IEEE Computer Society, with permission.

car horn (an auditory icon), resulted in a reduction of braking latencies of around 400 ms when compared to the no-warning signal baseline condition. This figure compares very favorably with the half-second reduction in braking RTs that Suetomi and Kido (1997) estimated would be sufficient to lead to a 60% reduction in FTRE collisions. That said, further research will be needed before any more valid suggestions within an ecological context can be made. For one of the crucial limitations with Ho et al.'s study, as with the majority of other studies that have been reviewed in this chapter, is that the warning signals were presented far more frequently than would be expected in any realistic situation (cf. Lee et al., 2002). In future studies, researchers will therefore need to confirm that the benefits in braking RTs documented thus far hold up under more realistic driving situations (cf. Ho & Spence, 2008; Spence, 2012a; Tufano, 1997; Van Erp et al., 2007). It will also be important to assess the effect of different levels of false alarms given the "cry wolf" phenomenon mentioned earlier in the chapter (Breznitz, 1983).

One final concern here relates to the issue of risk compensation (Evans & Graham, 1991; Peltzmann, 1975). For, as has been seen previously in the case of the introduction of many other safety technologies in vehicles, initial safety gains can sometimes be offset by the apparent risk compensation that many drivers engage in (Wilde, 1982; though see Lee, 2008). That is, it seems as though many drivers actually try to maintain a certain (presumably what they feel is acceptable) perceived level of risk (Spence, 2012a). Thus, the danger here is that the drivers of those vehicles that have been fitted with the latest tactile or multisensory collision avoidance warning signals might simply decide to take their eyes off the road more often than they already do (perhaps to check their email or SatNav; Ashley, 2001), believing that their in-car technology will (or at least should) alert them in time should they need to return their attention to the road ahead!

10.5 Reducing the workload of the overloaded driver

Van Erp and Van Veen (2004) investigated whether it would be possible to present navigational information to car drivers, via the sense of touch, via a visual display, or by the combined use of vision and touch. Navigational messages consisting of the distance to the next waypoint and the direction to turn (left or right) were presented to experienced drivers in a driving simulator study. The tactile stimulators (two rows of vibrotactile stimulators) were embedded in the driver's seat; the visual display consisted of simple symbols presented via an in-car navigation display. Van Erp and van Veen reported that drivers responded more rapidly following the presentation of multisensory (that is, combined tactile and visual) navigational messages than following the presentation of either signal when presented unimodally. However, it is also worth bearing in mind here that the lowest ratings of mental workload occurred in the touch-only condition, as compared to when the drivers attempted to use the unimodal visual or the multisensory displays. This latter observation may relate to the fact that while the tactile stimuli was presented to the driver's thigh, visual information was presented from a display situated away from the driver's body (i.e., the visual and tactile information were presented from very different spatial positions—that is, they were not co-localized; see Ho & Spence, 2008). In laboratory studies, participants normally find it significantly harder to divide their spatial attention to different locations than to direct it to the same spatial location when they process multisensory information (see Spence & Driver, 2004; Spence & Read, 2003).

In another study, Lee and Spence (2008) had participants in a simulated driving task attempting to avoid potential accidents on the road ahead while at the same time trying to operate a touch-screen device (e.g., a mobile phone). Drivers reacted more rapidly (by braking) to the car in front when given trimodal feedback (consisting of tactile feedback from the touch-screen, together with visual feedback from the screen, and auditory feedback from a loudspeaker placed just behind the

screen; i.e., when all of the feedback was presented from the *same* spatial location). Performance decreased somewhat when the participants were given either unimodal visual or bimodal (either visuotactile or audiovisual) feedback in response to their button-presses. In this study, note, the participants actually rated their subjective mental workload (as measured by a standardized workload questionnaire) as being significantly lower in the multisensory as compared to the unimodal feedback condition (see also Chen & Terrence, 2008).

In fact, when reviewing the applied literature in this area it is striking that a number of the applied studies that have been published to date have failed to demonstrate any particular benefit associated with the presentation of multisensory as compared to unisensory tactile information displays or warning signals (e.g., Fitch et al., 2007; Lee et al., 2006; Van Erp & Van Veen, 2004). It is, though, critical to note that the various unisensory components of the multisensory signals used in most of these studies were actually presented from different spatial locations. Indeed, the available cognitive neuroscience research suggests that such conditions can actually lead to multisensory suppression (where one stimulus leads to a participant, or interface operator, neglecting the other) rather than multisensory facilitation (Stein & Stanford, 2008). It is particularly interesting that those studies that have demonstrated a significant advantage of multisensory over unisensory tactile displays (showing that multisensory displays and warning signals can significantly reduce both braking latencies, Ho et al., 2007a, and subjective workload, Lee & Spence, 2008, presented the stimuli from the different sensory modalities from the *same* direction or spatial position).

Ho et al. (2009) explicitly manipulated the spatial correspondence between the auditory and tactile components of a multisensory warning signal in order to determine what effect it would have on the performance of their participants. Intriguingly, multisensory facilitation was observed *only* when both the auditory and tactile cues came from the same direction (either on the left or on the right of the participant), but not when one signal was presented from the side while the other signal was presented from straight-ahead. Such findings highlight the potential importance of spatial correspondence for multisensory interface design (see also Spence & Driver, 1997, 2004; Spence & Read, 2003). Ho et al. themselves suggested that it might be sufficient for the various components of a multisensory warning signal to be presented from the same spatial direction, not necessarily from exactly the same location, in order to give rise to multisensory facilitation effects (Ho & Spence, 2008).

10.6 On the future of tactile information displays for drivers

Given that there seems good reason to believe that tactile and/or multisensory displays are here to stay, one might ask what the future holds in terms of in-vehicle display design. One important issue here relates to the limitations on information transfer via the skin. That is, just how much information can be transmitted to the “visually-overloaded” driver (see Spence & Ho, 2008b) by means of tactile and/or multisensory displays? While there have been some interesting developments in this area over the course of the last decade or so (e.g., see Fitch et al., 2011; Hempel & Altinsoy, 2005; Jones et al., 2006; MacLean, 2008; Yanagida et al., 2004), research has now shown that, at least in the absence of prolonged training (again, not a practical option for most drivers), tactile information processing across the body surface is surprisingly limited (see Chapters 3 and 4). For example, as we saw in an earlier chapter, without extensive training people simply cannot count more than two or three tactile stimuli when presented simultaneously across their body surface.

What is perhaps more important here is that the sudden presentation of a visual (or for that matter tactile) stimulus can also make people effectively “blind” to any changes taking place

in the pattern of tactile stimulation that happens to be presented across their body surface (or hands; see Chapter 4). Even unambiguous directional tactile signals (such as those elicited by the movement, or apparent movement, of tactile stimulus across the skin) can be overridden by the simultaneous presentation of visual or auditory stimuli if they happen to be moving in a different direction (Lyons et al., 2006). Such findings lead to the worrying suggestion that the presentation of one warning signal, or information display, might eclipse, or extinguish, a driver's awareness of another warning signal (see also Ferris et al., 2010).

Given these fairly severe limitations on tactile information processing, it remains to be demonstrated whether more complex tactile displays will necessarily have much of a place in the commercial vehicles of the future (though see Jones & Sarter, 2008; Nagel et al., 2005, for some intriguing developments in other areas where the need for extensive training is unlikely to prove so problematic for the take-up of tactile interfaces). Researchers have recently started to demonstrate that meaningful tactile icons can be used to convey more complex information to an interface operator, at least when they had been given sufficient training (see also Chan et al., 2005; Luk et al., 2006; MacLean, 2008; MacLean & Enriquez, 2003; Tang et al., 2005). Though remember that this is something that the car companies are convinced that it will be hard (if not impossible) to convince potential car owners about.

What is more, the drivers (at least of manual cars), unlike the participants in the majority of laboratory studies, are often likely to be in a state of near-constant motion as they brake, accelerate, change gear, check their mirrors, etc. Importantly, the latest research from the psychophysics laboratory has demonstrated that when planning, or executing, a movement, such as turning the steering wheel, people show much reduced sensitivity to tactile stimuli (Gallace et al., 2010; Juravle et al., 2010, 2011; Juravle & Spence, 2012; Van Hulle et al., 2013; see also Chapter 9). This form of movement-induced sensory suppression appears to be restricted to the tactile modality (Juravle & Spence, 2011), and as such, it may reflect a heretofore unconsidered limitation on the utilization of unimodal tactile interfaces (though see also Pritchett et al., 2011). In a laboratory-based study that directly investigated this topic within a simulated driving task Gallace, Zeeden, Röder, and Spence (2010) had participants detect changes between consecutive patterns of tactile stimulation presented on their body. In half of the trials the participants had to turn a steering wheel either clockwise or anticlockwise. The participants in this study failed to detect tactile changes while performing this task more often than when they were not turning the wheel. This effect was even more pronounced when the stimuli were presented on the participants' arms than when presented on their legs.

One other potential limitation with tactile (and to a lesser extent auditory) displays that needs to be borne in mind when considering what happens when considering the utility of such signals for drivers who move, is that changes in eye/head position have been shown to shift the perceived localization of tactile (and auditory) signals (e.g., Harrar & Harris, 2009; Ho & Spence, 2007). However, it turns out that such mislocalization errors are only in the order of a few degrees. This means that they shouldn't have too much of a detrimental effect on a driver's ability to interpret the direction signified by a tactile (or auditory) warning signal when their gaze is diverted (e.g., as when diverting their gaze to check the passenger side wing mirror).

10.7 Conclusions

In the review of the literature on tactile and multisensory interface design covered in this chapter, we have tried to highlight the relevance of the latest cognitive neuroscience research to contemporary interface design. In particular, we have focused on the design of in-vehicle (specifically

in-car) warning signals and information displays. It now seems increasingly likely that developments in the field of cognitive neuroscience, particularly those related to the topic of attention, will have an increasingly noticeable impact on the design of tactile and multisensory interfaces in the next few years (e.g., Ferris et al., 2006; Ferris & Sarter, 2008; Spence & Driver, 1997). In fact, the first cognitive neuroscience-inspired design principles for interface, and warning signal, design have already now started to make their appearance out there in the marketplace (Ho & Spence, 2008; Previc, 2000; Spence & Ho, 2008b; cf. Sarter, 2007; Spiers & Maguire, 2007; Stanney et al., 2004). Such developments are sometimes described under the header of “neuroergonomics” (e.g., Fafrowicz & Marek, 2007; Parasuraman & Rizzo, 2006; Spence, 2012a), though one should certainly be cautious of any field of research that introduces the *neuro-* prefix (see Legrenzi & Umiltà, 2011; Spence, 2012d).

More research will, though, be needed in order to better understand the potential trade-off between graded warning signals, that may be less annoying, but at the same time less immediate, than abrupt onset signals, and the fast reactions that are typically required in response to such warning signals (cf. Gray, 2011). Additionally, given the specific constraints of the commercial vehicular setting, another important question concerns whether more “intuitive” tactile icons can be developed that somehow convey their meaning without the need for extensive (or, ideally, any) training on the part of the driver (or drivers) of a car. The hope here is certainly that novel tactile displays will be able to convey their meaning without the need for training (one of the limitations when working with tactile displays for regular road users). As we saw earlier in this chapter, one way in which to achieve this might be through the incorporation of everyday affordances into the design of the tactile stimuli themselves. More information is also needed regarding how the issue of compliance vs. reliance (see Dixon et al., 2007), or the “cry wolf” phenomenon (associated with the presentation of signals that are perceived as false alarms; Breznitz, 1983), influences the effectiveness of tactile and/or multisensory warning signals (Baldwin et al., 2012).

Having discovered which signals (or which stimulus parameters) work most effectively when presented with both a high reliability and very frequently in the driving simulator (and laboratory) research outlined in this chapter, researchers will, in the coming years, need to follow-up with additional research in order to ensure that those signals still deliver genuine performance/safety benefits to drivers even when they aren’t always reliable (Baldwin et al., 2012; Bliss & Acton, 2003), and when they are presented very infrequently. Understanding how our brains process and react to information conveying potentially dangerous meanings, will also be of help for building safer and more effective warning systems for drivers and interface users.

Given the very limited number of on-road studies that have involved the presentation of tactile or multisensory warning signals, this will also be another area for future research (cf. Santos et al., 2005). Of course, one should not forget the potential ethical implications of what would happen should a participant/driver have an accident while on the road in such a study. Given that it is currently unclear who would be responsible in such a situation, a number of researchers have argued that high-fidelity simulator studies may currently offer the best environment in which to evaluate any new tactile or multisensory driver technology (Haigney & Westerman, 2001; Ho & Spence, 2008).

Another important research area concerns the presentation of multisensory (i.e., audiotactile and/or audiovisual) warning signals and information displays. Further research is currently needed in order to determine whether there may be certain regions of the body surface (or in the space surrounding the body) where tactile/multisensory warning signals are especially effective (see, for example, Ferris & Sarter, 2011)? For example, cognitive neuroscience research conducted over the last decade or so has demonstrated that audiotactile multisensory interactions in neurologically

healthy adults are qualitatively different in the region close to the back of the head than elsewhere (Kitagawa et al., 2005; see Occelli et al., 2011, for a review). Ho and Spence (2009) have demonstrated that the presentation of near-rear auditory warning signals result in drivers returning their gaze to the center from the periphery (e.g., as when checking the wing mirrors) significantly more rapidly than a tactile warning signal, or an auditory signal presented from another location. Such results support the view that the space immediately behind a driver's head is also dealt with in a seemingly special way while they are driving. Such results also hint at the possibility that psychologists will, in the future, need to make sure that they assess drivers' performance using driving-relevant actions (e.g., head-turning, braking etc., rather than necessarily always relying on speeded manual button pressing responses).

Another intriguing area for future research will be to determine just how important the spatial coincidence and temporal synchrony of the individual sensory signals are to the effectiveness of real-world multisensory displays (cf. Ho et al., 2013). In other words, just how similar does the position/direction from which the various unisensory stimuli are presented need to be in order to deliver significant benefits from the utilization of a multisensory warning signal? The latest evidence suggests that, at least for the case of audiovisual signals, desynchronized multisensory warning signals are no more effective than synchronized ones (see Chan & Chan, 2006; Spence & Driver, 1999, on this issue). Whether the same is true for audiotactile or visuotactile warning signals is a question that again awaits future research.

One final area where more research is most definitely needed relates to trying to understand how to design tactile (and multisensory) warning signals that are optimized for the growing population of older drivers. This group now constitutes the most rapidly growing section of the driving population (see Waller, 1991). It has been estimated that there will be more than a billion people over the age of 60 years by 2020 (Spence & Ho, 2008a). This is a particularly worrying statistic given the significant increase in the risk of an accident that has been observed in drivers once they reach the age of 55 years. Ergonomists (and increasingly neuroergonomists) will therefore need to start focusing more of their research efforts in the coming years on the design of warning signals and interfaces targeted specifically at the older driver (cf. Becic et al., 2012; Strayer & Drews, 2004), given their likely patterns of sensory decline (Kline & Scialfa, 1997). It is noticeable how much of the literature assessing the effectiveness of warning signals has been conducted on a fairly narrow demographic (cf. Henrich et al., 2010). That said, one recent finding that holds particular promise with regard to the slowing of responses that is often seen in elderly drivers comes from Laurienti et al. (2006). They reported that while elderly participants (with a mean age of 71 years) responded to unisensory targets significantly more slowly than did a group of younger participants (mean age of 28 years), they were nevertheless able to respond to multisensory targets as rapidly as the younger participants were able to respond to the unimodal targets. Such results therefore suggest that multisensory warning signals and displays may represent a particularly effective means of supporting safe driving in older drivers. Given the findings reported earlier in this chapter (Ho et al., 2007a), it will obviously be particularly interesting to see whether older drivers also benefit more from the presentation of spatially colocalized audiotactile warning signals, when compared to their unimodal component parts (see also Chapter 9, on sensory augmentation for the elderly). In Section D of the book, we will consider the role of the more affective aspects of touch in applied research.

Section D

Touch in the real world 2: Enhancing the affective design of touch

Touch in the marketplace: Selling by means of touch

Delight of the hand was a secret that the primitive craftsman knew well. How an African wood carving or a bit of ancient pottery snuggles in the palm! Those who have to do with designing for mass production by the machine will do well to go to the museums and study the handiwork of those early men who loved the feel of things in their hands. The sense of touch may prove to be one of the best salesmen once we have relearned its secrets.

(Sheldon & Arens, 1932, p. 102)

After the eye, the hand is the first censor to pass on acceptance, and if the hand's judgment is unfavorable, the most attractive object will not gain the popularity it deserves. On the other hand, merchandise designed to be pleasing to the hand wins an approval that may never register in the mind, but which will determine additional purchases. The deciding factor in the purchase of an automobile may be not free-wheeling, or chromium accessory gadgets, but the feel of the door handles, the steering wheel, upholstery. A type-writer, a fountain pen, a book, a pipe, a cigarette, a compact—their use and particularly their re-use are largely determined by their feel in the hand. Make it snuggle in the palm.

(Sheldon & Arens, 1932, pp. 100–101)

11.1 Introduction

As the opening quotes suggest, people have argued for many years that what a product feels like can influence whether or not people will end up buying it. Think, for example, of an expensive piece of jewelry or a wristwatch; we can appreciate its beauty visually, but our final purchase decision often comes only after we have handled it. Indeed, most likely, we will not purchase a particular product if it doesn't fit with our idea of how it should feel when held in the palm (e.g., an expensive piece of jewelry should be heavy and have a solid feel that provides information about the stone or metal that the item has been made from; cf. Lindstrom, 2005, 2008). This is

especially true for those products that are likely going to come into close contact with our skin (such as clothing, bed linen, pillows, shoes, etc.; see McCabe & Nowlis, 2003). Indeed, people often rub the materials/clothing that they are considering purchasing against their cheek, a part of the body with high degree of tactile sensitivity (e.g., Weinstein, 1968), in order to evaluate their warmth, softness, and/or quality (Underhill, 1999).¹ As seen in Chapter 1, marketing research conducted by Millward Brown has confirmed the importance of touch when evaluating certain hand-held items by showing that 35% of consumers reported that the feel of a mobile phone was actually more important than its look (see “*Does it make sense?*,” p. 44). Results such as these seem, at least in part, to reflect the fact that the tactile attributes of a product constitute an important part of our expectancy (and therefore also of possible judgments of novelty) regarding the objects that we use on a daily basis (see Schifferstein & Spence, 2008). These considerations have led to the suggestion that the more intelligent exploitation of the sense of touch by marketers might, then, exert a profound impact on consumer behavior (Sheldon & Arens, 1932; Underhill, 1999). Indeed, research by McCabe and Nowlis (2003) found that consumers prefer to select products from retailers who specifically allow their products to be touched.

As seen already back in Chapter 1, touch is the first sense to develop in infants and there is definitely something that brings us back to our earliest days when we handle new or rare objects (just as we used to do with new toys). Touch is also a sense that can convey meaning and content that cannot easily be transmitted through more formal language (e.g., Montagu, 1971). As a consequence, the possibility of using touch more effectively with marketing purposes in mind has started to become ever more appealing. The growing use of images and product/brand labels to evoke (or at least to remind people of) tactile sensations in many advertising campaigns in recent years would seem to suggest an increasing awareness of the great potential of touch in marketing (for example, see the sensory special issue of *Harrods Magazine*, published in February, 2008). Or take the 2010 marketing campaign by Unilever for their “Surf” fabric conditioner: Here, visual images (involving models touching soft materials) are used to “evoke” the softness of the results that can be obtained by using the product (see also section 11.2.1; see Sheldon & Arens, 1932, for a number of similar examples from the last century).² Similarly, Cadbury Trebor Bassett, used a number of images to suggest the fresh sensations elicited by cold water falling on the skin in order to promote their “Trident Soft” chewing gum. In other cases, even the name of the product has seemingly been chosen to remind the potential consumer of certain specific tactile sensations: For instance, take “Feu d’Orange Soft Skin Oil” by L’Occitane, “Soft Cashmere Tea” by Lipton, and “Dualit Soft Touch” by Dualit Limited, etc. (see Table 11.1).

In other cases, the advertisers have attempted to get their potential customers to engage in some sort of tactile interaction with the product or samples of it (<<http://www.thegraphicdesign-school.com/blog/advertising/when-times-are-tough-graphic-designers-get-tactile/>> downloaded on October 18, 2012). This is increasingly frequent in those products advertised in magazines (a media once dedicated only to visual forms of communication). One clear example of this new form of product advertisement comes from the make-up line “Addict” by Dior. Here, the advertisers glued a sealed envelope to one of the pages in the magazine. The envelope has a seal that

¹ Here one might wonder if the use of the cheek rather than of the fingertips (an area of the body with a similar sensitivity) is related to the fact that the cheek is a hairy region of the skin (perhaps innervated more by CT afferents fibers; see Chapter 2).

² Those Italians who are old enough might remember “Coccolino,” a soft teddy bear that was used in the 1970s to 1980s to advertise the homonymous fabric conditioner in Italy.

Table 11.1 A selection of visually advertised products in the last years where the sense of touch has been evoked by means of different strategies.

Name of product	Category of product	Brand	Touch evoked by	Sensations aimed to be reminded of
Gain	Fabric conditioner	P&G	Verbal description on product	Softness to touch
Soft Touch Quick Dry	Fabric conditioner	Sanmex International	Name of product	Softness to touch
Mavala Soft Touch Straight Tweezers	Beauty care	Feelunique	Name of product	Softness to touch
Feu d'Orange Soft Skin Oil	Beauty care	L'OCCITANE	Name of product	Softness on the skin
The Dualit Soft Touch	Household item	Dualit Limited	Name of product	Softness to handle
Soft Cashmere Tea	Beverage	Lipton	Name of product	Lightness to drink
Lenor ¹ Summer Breeze	Fabric conditioner	Procter & Gamble	Synesthetic/Name of product	Softness to touch, freshness to smell
Surf	Fabric conditioner	Unilever UK	Synesthetic	Softness to touch, freshness to smell
Trident Soft	Chewing gum	Cadbury Trebor Bassett	Synesthetic/Name of product	Body Refreshment
Soft Touch	Motorbike helmet	Piaggio	Name of product	Softness to wear
Silk Epil	Epilator	Braun	Name of product	Softness to use (and softness of the skin after product use)

¹ The most recent Lenor campaign in the UK has also made use of the expression "I feel good in Lenor," something that clearly reminds one of the importance of tactile sensations in the clothing that one wears.

needs to be opened in order to see what is inside (basically an invitation to try the product). By using such a strategy, the advertiser was able to prompt the reader of the magazine (by acting upon his/her curiosity) to engage in some tactile/haptic interaction with the product. That is, this simple tactile interaction can be said to make the relationship between the brand or product and the consumer more intimate than can ever be obtained with the more traditional visual means of communication (especially considering the fact that we often feel ambivalent and disconnected from mass-manufactured goods).

Recent technological developments mean that it is now much cheaper and quicker than ever before to prototype novel packaging designs, and to deliver novel product coatings/feels (e.g., see Anon, 2010; Raine, 2007; "Touch looms large as a sense that drives sales," 1999). As a consequence, over the last decade or so, a growing number of companies have started to diversify the kinds of tactile experiences that they are delivering to those consumers who choose to interact haptically with their products. For example, an increasing number of plastic containers for household beauty products now incorporate "soft touch" resins that provide a particularly soft and pleasurable feeling when held in the customer's hand. Indeed, the members of one focus group who tried such packaging for Clairol's Daily Defence shampoo described the experience as being "almost

sexy”; And, hard though it is to believe, they were apparently reluctant to let go of the packages after having been introduced to them (see “Touch looms large as a sense that drives sales,” 1999). Or, take the example of “Alli,” the fat-blocking pill released in the United States in 2006; This pill was presented in a pillbox that could be opened with only one hand (cf. McDaniel & Baker, 1977), and which has been made with soft rubber and careful texturing that is especially pleasing to the touch (see Johnson, 2007). What is more, lacquers can also now be printed onto standard packaging in order to give a textured (i.e., rough or smooth) feel (Raine, 2007). Innovation in consumer electronics are also increasingly being linked with the “feel” of the product: Take, for example, the Apple iPod. According to Johnson (2007), the innovative feel of the case of this product has now created a new standard for portable electronic equipment. As David Howes (2005) has noted, playing with a product’s feel provides an additional means of differentiating one’s product from the competition (see also Lindstrom, 2005).

It is important to point out here that a customer’s tactile experience of a product (and/or its packaging) can be manipulated simply by changing its shape and/or surface feel. These macrogeometric and microgeometric stimulus properties (see Gallace & Spence, 2009; Spence & Gallace, 2008) are both likely to be important in terms of their potential influence on a customer’s final (multisensory) product evaluation (Spence & Piqueras-Fiszman, 2012). The focus in this chapter, though, will primarily be on the surface properties of the stimuli, given that less is currently known about the effects of changing the shape of products on people’s hedonic appreciation of them (see Etzi, Spence, & Gallace, in preparation; though see Bloch, 1995; Lindauer, 1986; Lindauer, Stergiou, & Penn, 1986).

The last few years has seen a number of exciting (and very successful) developments in the tactile aspects of product design: For example, the development of ever-cheaper coating technologies has meant that it is no longer as expensive as it once was for companies (and hence, brand managers) to give their product or its packaging a surface “feel” that is multisensorially congruent with the overall brand image. In fact, prices have now dropped so much that it is almost as easy to change the “feel” of a product as it is to change the color and/or other visual aspects of the packaging design. For example, a few years ago, the makers of Velvet toilet tissue packaged their product in a protective plastic wrapping that had been specially treated to give it something of the feel of real velvet, hence ensuring that the tactile feel of the product’s packaging was semantically congruent with the overall brand image. Similarly, some years ago, Hovis experimented with treating the packaging of their crustless bread with a soft-touch lacquer in order to suggest the softness of the bread within (see also Brown, 1958). A number of companies have even gone so far as to consider trade-marking the signature “feel” of their brands in order to help distinguish them from the opposition at a more emotional and/or affective level (see Howes, 2005; Lindstrom, 2005; Schifferstein & Spence, 2008). The fruit juice container designed by Naoto Fukusawa, a Japanese product designer gives some sense of just what is possible these days in terms of hyper-realistic packaging (see Figure 11.1a–c). Compare this packaging with the more traditional Jif lemon juice container that captures the macrostructural shape of a lemon, but which fails to deliver on the microstructural features regarding fine surface texture (see Figure 11.1d). Considering that, in the last few years, more than 30% of the world’s biggest brands have been working on “sensory branding” strategies (Johnson, 2007), touch is likely to offer numerous opportunities for innovative branding and marketing in the years to come.

How can companies deal with the challenges and opportunities? How can they use the knowledge arising from the neuroscientific study of touch to design new products and their packaging? In this chapter, a number of the key ways in which many companies are now beginning to harness the latest insights from the burgeoning field of cognitive neuroscience in order to design

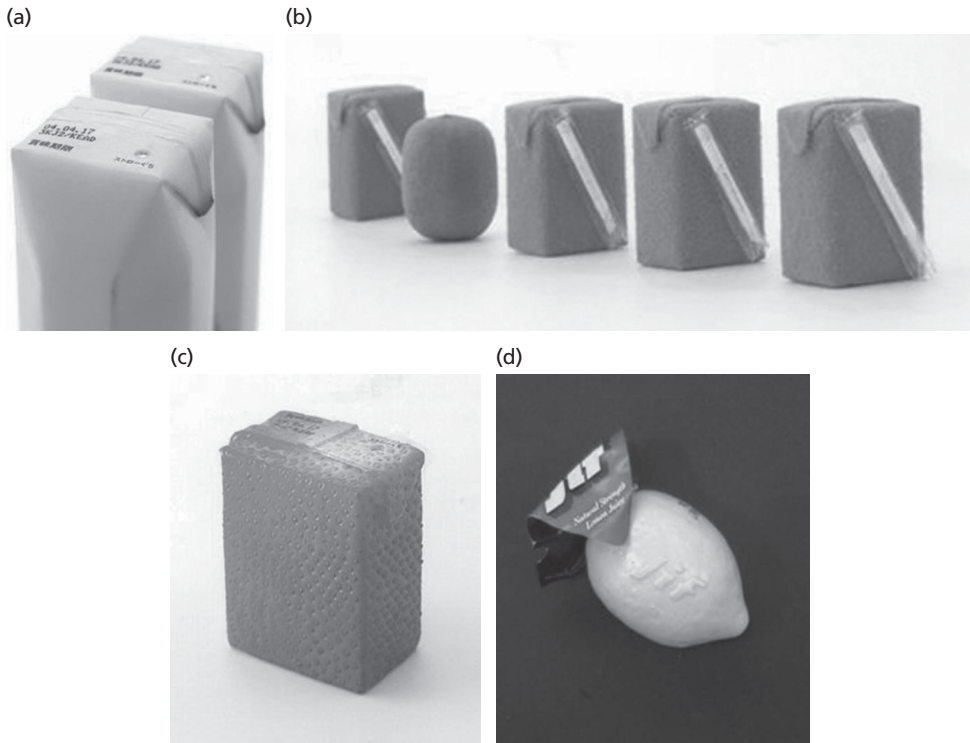


Fig. 11.1 (a–c) “Juice Skin” by the product designer Naoto Fukusawa for TAKEO PAPER SHOW 2004- HAPTIC directed by Kenya Hara. The photographs show a range of prototype drinks containers that illustrate the possibilities associated by incorporating the texture of the fruit flavor of the drink into the packaging (d) The “Jif” lemon juice container. While this traditional pack captures the macrogeometric attributes of a lemon, it is less successful at capturing the microgeometric surface texture. © 2013, Unilever Food Solutions.

the tactile attributes of their products are highlighted. Over the last decade, research has led to a rapidly growing understanding of the mind of the customer. The research reviewed in this chapter will look at what marketers can do in order to try and alleviate, or circumvent, the problems associated with the likely on-going lack of tactile experience resulting from the increase in Internet-based purchasing and from the growth of the aging population. Here we forward a cognitive neuroscience-inspired explanation for how, and why, tactile stimulation may have such a dramatic effect on multisensory product evaluation in terms of the notion of *affective ventriloquism*. Finally, we critically evaluate what advertisers and marketers can, and in some cases already are, doing in order to “stimulate” (or, at the very least, appeal to) the consumer’s sense of touch, given the audiovisual nature on most (electronic) communication media (see Johnson, 2007; Lucas & Britt, 1950). Note that the present review will not deal with the literature that has investigated the role played by the more interpersonal aspects of touch on marketing, product evaluation, and ultimately on sales (and that has shown that touch can strongly affect people’s compliance with specific requests; e.g., Guéguen & Jacob, 2006; Hornik, 1992; see Chapter 7).

11.2 Tactile product design

Designing products that “feel” good in a potential customer’s hands, or on whichever part of their body that they are likely to come into contact with, actually has a surprisingly long history. Back in 1932 (and just after the great stock market crash), the importance of making products feel good was stressed by Sheldon and Arens (1932); Egmont Arens, director of the Industrial Styling Division of Calkins and Holden and his colleague Roy Sheldon, championed an approach to product design known as “*consumer engineering*” (or “*humaneering*” after John Dewey who first coined this term; see Sheldon & Arens, 1932). This was defined in terms of a business tool for designing products that more closely addressed the tastes and/or needs of the typical consumer (Calkins, 1932). Thirty-five years later, Donald Cox (1967) highlighted the importance of lining the pockets of fur coats in materials that were pleasing to the touch in order to promote sales. The reader might find it surprising that someone should care about changing the feel of something that the majority of the customers would probably not even notice. Still, this example clearly demonstrates an early interest in changing apparently insignificant details of the tactile design in order to improve (perhaps implicitly) the customer’s perception of the product. This approach, though has been echoed more recently by Helander (2003) who pointed out that a consciously built-in “good feeling” to a product can be all that it takes to trigger the final purchasing decision. However, although the importance of tactile stimulation in shopping behavior has been mentioned periodically over the years (e.g., Cox, 1967; Fiore, 1993; Holbrook, 1983; Spence, 2002b); the majority of product design efforts have, at least until recently, been directed toward the customers’ other senses—that is, toward the visual, olfactory, and, where appropriate, gustatory aspects of product design/marketing (e.g., Ellison & White, 2000; Neff, 2000; Trivedi, 2006; though see Barnes & Lillford, 2006; Nagamachi, 1995; Schütte, Eklund, Ishihara, & Nagamachi, 2008).

Nevertheless, research by Schifferstein and Desmet (2007) has started to quantitatively assess the importance of each sensory modality to people’s evaluation of a variety of products while in use (see also Demir, Desmet, & Hekkert, 2009; Schifferstein, 2009a, b, 2011). The participants in Schifferstein and Desmet’s study had to interact with products when a given sensory modality was “blocked”: Vision was blocked by blindfolding the participant; touch was blocked (at least partially) by making the participant wear thick, inflexible, oven gloves, and so on. The results revealed that if the feel of a product was limited, participants tended to report stronger feelings of “alienation” than if they could not see the product. That is, the lack of touch (more than the lack of vision) resulted in participants perceiving familiar products as being foreign! Schifferstein and Desmet’s results might therefore be taken to suggest that a person’s familiarity with a given product is heavily based on its tactile attributes.³ Note, though, that one limitation with this research is that the procedures used for blocking the sense of touch actually also (perhaps necessarily) affected the “usability” of the items as well. Therefore, the results of Schifferstein and Desmet’s research (as far as the sense of touch is concerned) could, at least in part, simply reflect

³ It would therefore be an interesting question for future research to determine whether, in the absence of vision, the haptic feel of a Coke bottle would be judged as any more familiar than the feel of any other branded product? While it has often been asserted that it would, it seems, at present to represent an empirical question, one that is in need of experimental investigation. Note here that just because one feels, intuitively, that an object is familiar does not mean that it will necessarily be judged as such by people (see, for example, Willemin & Richardson, 1982, for one dramatic demonstration that people can sometimes even fail to recognize something as seemingly familiar as the back of their own hand).

the fact that participants were not able to use the products properly whilst wearing the inflexible gloves. As such, it will be important in future research to investigate the possibility of evaluating the contribution of the tactile modality, independent of (although likely in interaction with) the usability of a product. Furthermore, given the results of earlier laboratory research identifying the many different kinds of exploratory strategies that people use when trying to evaluate the specific tactual properties of objects (Klatzky, Lederman, & Metzger, 1985), it would be interesting to investigate whether or not wearing the oven gloves had the same effect on all of these different kinds of exploratory behavior. Taken together, the research reported in this section therefore constitutes a selection of isolated examples in the extant literature on the psychology of sensory marketing and product evaluation (see Solomon, Zaichkowsky, & Polegato, 1999). By contrast, a much larger body of research has addressed the visual, and, more recently, the auditory, aspects of product design and marketing (e.g., Byron, 2012; Hekkert & Schifferstein, 2008; Spence, 2002b, 2011a; Treasure, 2007; see also Mostafa, 2012). In the years to come, researchers will need to investigate how to manipulate the tactile aspects of a given product together with its visual, and where relevant auditory, olfactory, and gustatory properties, in order to obtain products that have a multisensory appeal to as many customers as possible (Krishna, 2010, 2012). The importance of engaging several of a customer's senses, and of doing so in a multisensorially congruent manner to develop product appreciation/loyalty, is, though, increasingly being recognized (see de Chernatony & McDonald, 1992; Lindstrom, 2005; Neff, 2000; Spence, 2002b, 2011a; Springer, 2008). The drive toward congruent multisensory stimulation is becoming all the more important given recent findings showing that it can lead to better memory recall than does unimodal stimulation (e.g., Lehmann & Murray, 2005; see Gallace & Spence, 2009, for a review).

11.2.1 Modeling multisensory product perception

What is particularly exciting here is that mathematical models have recently been developed that allow researchers to predict how the cues provided by each of the senses will be combined in order to give rise to the perception of the specific multisensory attributes of an object/product (see Ernst & Bühlhoff, 2004; Trommershäuser, Landy, & Körding, 2011, for reviews; see also Chapter 7). While, to date, the majority of this research has been focused on the perception of the sensory-discriminative attributes of objects, such as their shape and size (Ernst & Banks, 2002), there seems to be no reason why such an approach could not be extended to model (and hence predict) people's more affective/hedonic product responses as well. Indeed, there may be a useful analogy here in terms of the ventriloquism effect, originally used to describe vision's influence over auditory localization (i.e., as is observed when we mislocalize the source of the ventriloquist's voice toward the articulating lip-movements of his/her dummy; Radeau, 1994). Of particular relevance here are recent findings showing that "*affective*" (or "*hedonic*") *ventriloquism* occurs in the emotional domain as well (see Tanaka, Koizumi, Imai, Hiramatsu, Hiramoto, & de Gelder, 2009; see also Maiworm, Bellantoni, Spence, & Röder, 2012, for the observation that the emotional valence of short auditory and visual vocalizations affects the ventriloquist effect), as when people are asked to rate how happy or sad a person that they can both see and hear speaking seems to be. By independently manipulating the emotion of the seen face, and the emotional content of the voice, researchers have been able to assess the relative contribution of each sensory modality to people's affective judgments (e.g., see de Gelder & Vroomen, 2000; Dolan, Morris, & de Gelder, 2001). It turns out that people's perception of facial expression can be modulated by the emotional tone of the associated voice. It is our contention that such affective (or hedonic) ventriloquism effects can also be extended to the area of tactile and multisensory design (see

Spence & Gallace, 2011); In particular, to explain why it is that changing the *feel* of a product, or of its packaging, should influence people's overall multisensory product evaluation.

11.2.2 Maximum likelihood estimation in multisensory integration

As far as the laboratory-based research is concerned, it has been suggested that under conditions of multisensory stimulation, the sensory modality that carries the lowest variance (i.e., noise) in a person's estimate regarding certain qualities of a given stimulus is the one that will likely "dominate" or "drive" the perception of the inputs provided by the other senses; this is known as the maximum likelihood estimation (MLE) account of multisensory integration (first put forward by Ernst & Banks, 2002; see also Helbig, Ernst, Ricciardi, Pietrini, Thielscher, Mayer, Schultz, & Noppeney, 2012, for evidence concerning possible neural mechanisms of multisensory integration based on the weighted integration of stimulus features). Note, here, that the hairy skin seems to be specialized for the coding of affective responses (Field, 1998; Olausson et al., 2008; Spence, 2002b; see also Chapter 2 and 7); it might therefore be possible that touch will provide a less noisy estimate of a product's hedonic value than say audition or vision. Consequently, according to the MLE account of multisensory integration, it would be expected that tactile cues would dominate a customer's overall multisensory affective response to a product. As such, changing the pleasantness of the feel of a product or its packaging might be expected to have a more profound effect on the affective (or hedonic) response than changing any of the other sensory attributes of the product.

What is more, while many other product-related sensory (i.e., visual) cues have already been optimized over the years, less attention has thus far typically been given over to modifying the tactile attributes of products (in part, because it was always too expensive to modify this particular aspect of a product's design). This means that there may well be great room for improvement in terms of tactile innovation in product design. While such a proposition is clearly speculative at present, the key point to note is that the mathematical models that have been put forward to account for the data on spatial ventriloquism (e.g., see Alais & Burr, 2004) also do an excellent job at accounting for the integration of the macrogeometric visual and tactile cues contributing to an object's shape as well (see Ernst, 2006; see section 5.1). There is, at present, no obvious reason why these mathematical models could not also be successfully applied to the more hedonic qualities of the stimuli (although further empirical investigation on this topic will certainly be required).

11.3 The customer's need for tactile input

11.3.1 Touch hunger

A little over a decade ago now, Dr. Tiffany Field, the Director of the Touch Research Institute, in Miami, Florida coined the phrase "*touch hunger*" to describe the absence of tactile stimulation being reported by many people in society today (e.g., Field, 1998, 2001; see also Chapter 7). Since then, the true extent of the marketing opportunity offered by means of appealing to a consumer's skin, and the promise of delivering to that need, has become ever more apparent. Importantly, researchers have reported that consumers experience a greater need to touch certain classes of product prior to purchase than for others (Citrin et al., 2003; see also Lindstrom, 2005). For example, a survey study of more than 270 undergraduates on a university campus in the United States conducted by Citrin and colleagues revealed that the only product that students reported a significant need to touch (prior to making an Internet-based purchase) was clothes (see also

Underhill, 1999). By contrast, participants claimed that they would be happy to make Internet-based purchases of books, videos, compact disks, electronics, and/or flowers without necessarily having the opportunity to touch them first. There are, in fact, many other categories of product that customers never need to touch—when, for example, was the last time you touched a light bulb before you bought it (see Underhill, 1999, pp. 162–163)? As Gleckman (2000) puts it: “The lesson here is simple: I still want to see and touch a product before I buy it. Web sites are pretty good for selling books and airplane tickets. But they don’t do feel.” On the basis such considerations, one might predict that *novel and innovative* products that need frequent tactile interactions in order to be used are those where the tactile attributes are likely to play the most important role in purchase behavior. Following on from these considerations, an increasing number of clothing chains are now considering how to convey the distinctive feel of their fabrics by means of the Internet.

11.3.2 Touch as a useful tool in retailing

Although the available evidence suggests that tactile information is relevant to people’s evaluation of products, it is important to point out that even within a particular product category, there are likely to be significant differences in the relative importance of the tactile attributes of the product as a function of the brand concerned (we will come back to the topic of individual differences between consumers later). For example, Martin Lindstrom (2005) has pointed to the distinctive tactile branding of the traditional glass bottle of Coca-Cola, registered as a trademark by the U.S. Patent and Trademark Office in 1977, and to the satisfying weight of a Bang & Olufsen remote control when held in the hand (see also Lindstrom, 2008). That is, the consumer’s need to touch objects that he/she might want to buy varies markedly as a function of both the specific class of product and the particular brand concerned. One example of the importance of the tactile aspects of packaging design comes from the effect of the reintroduction of the traditional Coke bottle: Reports in the consumer target market suggested that sales increased by 12%, attributable in part to the reintroduction of Coke’s signature contour bottle (see Jones, 1999).

In another study, McCabe and Nowlis (2003) reported that consumers preferred to select those products from retailers who allowed their stock to be touched, especially products for which tactile input is important for evaluation (for example, clothing or portable electronics; cf. Gentile, Spiller, & Noci, 2007). “The Gap” clothing store has been very successful in making the most of such opportunities for tactile appraisal by their customers: Walk into any Gap store and you will see tables piled high with clothes, all positioned at an easy-to-touch height. What’s more, you will see many of the store’s clientele, happily touching the merchandise (Robinson, 1998, pp. 203–204; Underhill, 1999; see also Peck & Shu, 2009, for the report that touching an object or merely imagining touching it can increase the perceived ownership of that object by an individual). Similarly, in the last few years many electronics outlets such as the Apple Store and Best Buy have started to make the customers touch their products rather than leave them watching behind the display cases. For example, if you enter an Apple Store you will see that the PC screens have been tilted at a specific angle. The angle has been explicitly chosen in order to encourage customers to adjust the screen to their ideal viewing angle, thus touching the object while doing so (<<http://www.forbes.com/sites/carminegallo/2012/06/14/why-the-new-macbook-pro-is-tilted-70-degrees-in-an-apple-store/>> downloaded on November 2, 2012). Following on from such observations, the question for marketers then becomes one of how to convince potential customers to touch the objects that they are trying to sell. As far as this point

is concerned, Klatzky and Peck (2012) recently addressed this very question by asking their participants to rate the tendency of pictured objects to invite touch, or their “touch-ability.” Despite the differences found across sets of objects, in general the touch-ability declined as the textures of the objects became rougher and the complexity of the shape more extreme. Interestingly, the authors also reported that participants’ ratings were correlated with their need for touch (see section 11.4.5). That is, surfaces that appear visually smoother are likely those that invite being touched the most by a potential customer, even if subjective variables are also likely to affect the final behavior.

That said, one also needs to be aware that there is a flip-side to allowing tactile exploration, namely the possibility of “*tactile contamination*.” That is, while people like to touch certain products, that doesn’t mean that they like to purchase products that they believe to have already been fingered by someone else (why else, after all, do so many of us take a newspaper or magazine on the stand from anywhere but from the top of the pile?; see Argo, Dahl, & Morales, 2006). Perhaps such behavior is not so irrational when seen in light of Underhill’s (1999, p. 162) observation that store towels are touched by an average of six shoppers before someone puts them in their shopping basket. Furthermore, Robinson (1998, p. 179) has estimated that people actually buy less than 25% of the items that they touch in-store.

It is important to point out that the majority of studies mentioned thus far have made use of questionnaire-based procedures in order to evaluate people’s attitudes toward specific products. That is, they have measured the opinion of potential buyers with regard to the importance of touch in the purchase of a particular item. Given that many psychological mechanisms act at an implicit or even automatic level of information processing (e.g., Fitzsimons, Hutchinson, Williams, et al., 2002; Roediger, 1990; Schneider & Shiffrin, 1977; Sherwood, 1999),⁴ one might wonder whether such responses are necessarily representative of customers’ actual behaviors. That is, to the best of our knowledge, no field study has as yet investigated people’s buying behavior in a real shopping situation under conditions where they either were (or were not) allowed to touch the items that were for sale. Ultimately, sales figures are the only data that the brand manager is going to want to see (or believe). However, although there is virtually no publically available published field research that can be used to confirm the importance of touch in an actual retail context, a number of observations from the marketing sector do at least provide tentative support for the claim. For example, when the supermarket group Asda (UK) removed the wrapping from several brands of toilet tissue in its stores so that shoppers could feel and compare the textures, the sale of the in-store brand apparently soared, resulting in a 50% increase in shelf space for the line (Ellison & White, 2000). At present, very little is known about the psychophysiological correlates of people’s reactions when interacting with specific products (such as a possible change in heart rate and/or a pupil dilatation to the sight/touch of a particularly appealing product; though see Nagamachi, 1989). However, the recent development of easily portable Wi-Fi biosignal recording devices for ecological research will surely help to fill this gap soon (e.g., Picard, 2003).

⁴ This quote from Sheldon and Arens (1932) contributes to make clearer how important implicit judgments are in our everyday choices: “Every day the average person makes hundreds of judgments in which the sense of touch casts the deciding vote whether or not it rises into the consciousness. Seemingly unreasoned likes and dislikes, attractions and repulsions, may be accounted for by undercover decision made by this sense. Such simple judgments as the acceptance or rejection of a towel, washrag, hairbrush, underwear, stockings, hinge upon how these feel in the hands; their acceptance or rejection motivated by the unconscious” (p. 99).

11.3.3 Tactile properties and product evaluation

Grohmann, Spangenberg, and Sprott (2007) addressed the question of whether, and under what conditions, the presence of tactile input would positively affect consumers' evaluation of retail products. They reported a study demonstrating that tactile input (consisting of the active manipulation of products) did indeed influence people's product evaluations. As one might have expected, they found that tactile input had a positive effect on the evaluation of products with characteristics that were best explored by touch (e.g., the softness and texture for the evaluation of a pillowcase; Underhill, 1999). More interestingly, they also reported that the effect of touch was particularly positive for high-quality products; by contrast, tactile input generally had a negative effect upon participants' evaluations of lower-quality products. In terms of their marketing implications, such results therefore suggest that providing an opportunity to touch various products does not necessarily have an absolute effect on people's liking for them (i.e., touching poor-quality linen might actually lead to a more negative evaluation of the product with respect to a condition in which people are only allowed to see the product). This might suggest that, for a number of items, "tactile quality" should even come before "visual quality" in the mind of the product designer.

According to Grohmann et al. (2007), the effects of tactile input are best explained by an information-processing mechanism rather than in terms of a process based on affect. That is, the effect of touch should be related to the amount of information that this sensory modality provides to the cognitive processes leading up to the ultimate evaluation of the stimulus (or product), rather than to the affective value that touch carries. However, given the increasing number of empirical observations suggesting that touch provides a privileged pathway to affective responses (see Chapters 7 and 13), one might wonder whether or not this is really the case. Physiological measures of people's emotional state, such as their heart rate, electrodermic response, pupil dilation, and respiration, may be particularly helpful here (see also Nagamachi, 1989; Paiva, Prada, & Picard, 2007; Picard, 2003). However, it should also be noted that recent evidence has highlighted the affective contribution of tactile input to people's evaluative responses as well. In a fascinating study published in *Science*, Ackerman, Nocera, and Bargh (2010) have shown that a job applicant is evaluated more highly when his/her curriculum vitae has a heavy rather than light cover (even if the CV itself remained unchanged). That is, there seem to be strong evidence that certain tactile attributes of objects, even when not relevant to a given judgment, are still able to affect people's responses and behavior.

11.3.4 The role of packaging in product evaluation

As noted in the introduction of this chapter (see section 11.1), the last few decades have seen a rapid expansion in the development of novel packaging designs. For example, many of the most successful innovations in the beverage sector during the 1990s were associated with bottle design (e.g., think Snapple, Perrier, etc.; see Johnson, 2007; Miller, 1994). This led to the possibility (although still largely under-exploited) of varying the tactile, together with the visual, attributes of certain containers, say, in order to make them more appealing and identifiable to the customer (e.g., Jansson-Boyd & Marlow, 2007; see Figure 11.1a and Figure 11.2). Following on from this observation, one might wonder whether a change in the feel of a container would also affect people's evaluation of the product within. Everyday experience certainly suggests that this might be the case: Think only of how different it feels to drink wine from a plastic cup as opposed to from a wine glass (see Spence, 2011e; see also Hummel, Delwiche, Schmidt, & Hüttenbrink, 2003; Wansink & van Ittersum, 2005; see Chapter 14, for a discussion on this

Fig. 11.2 A can of Heineken beer with thermochromatic paint drops. This coating technology makes use of a thermochromic pigment that changes color when the temperature rises, and returns to its original color when the temperature drops (see <<http://175proof.com/triedandtested/the-dutch-touch/>> downloaded on November 6, 2012). Heineken Brouwerijen B.V., Amsterdam, 2013.



point).⁵ Looking again at the innovative conceptual drinks packaging highlighted in Figure 11.1, one might ask whether fruit drinks might not taste “fruitier” when served in containers whose texture matched the identity of the drink within. Indeed, some years ago, Cardello (1994, pp. 270–271) reported that the packaging a food happens to be served in can affect people’s expectancies regarding what the contents are likely to taste like. It can even affect how much food a person consumes (see Cardello, Maller, Bloom-Masor, DuBose, & Edelman, 1985; Kramer, Edinberg, Luther, & Engell, 1989; see also Chapter 14).

In terms of the macrostructural attributes of a product’s packaging, Cheskin (1957) long ago noted that people would pay more for ice cream packaged in cylindrical containers than when the same product was sold in rectangular containers instead, presumably because they expected that the ice cream would taste better in the former case. Such effects are likely driven by the crossmodal associations (be they implicit or explicit) that customers build up between product quality and packaging/container shape (successful packaging shapes then become what are known as “image molds”; Meyers, 1981). A similar explanation can also be put forward to explain the observation that Del Monte peaches purportedly taste better in a glass container rather than a can. People

⁵ Here it is worth mentioning that in the 2009 the packaging expert James Nash presented at the British edition of the *Dragon’s Den* (a program where the most interesting and potentially successful ideas are sponsored by a pool of investors) an innovative “cup-a-wine” packaging. That is, the wine was planned to be sold in a single portion plastic cup. The invention was rejected by the investors who suggested that the product would not sell well. A few years later, the very same product appeared in the UK supermarket chain marketed by Marks & Spencer. The packaging was used to contain Le Froglet Rosé, a wine named the Great Value Champion Rosé at The International Wine Challenge. This product seems to have taken off among customers with nearly a quarter of a million glasses sold in the 2 years after launch (see <<http://www.dailymail.co.uk/news/article-2215384/M-S-wine-Le-Froglet-Ros-sold-plastic-cup-dismissed-Dragons-Den-tacky-wins-wine-Oscar.html>> downloaded on November 2, 2012). It is unclear if this success is due to the practicality of the packaging, to the user’s curiosity, or to any other factors. Only time will tell whether this product will remain on the supermarket shelves for many more years to come. It would, however, be interesting to test if the wine in this packaging is perceived as of better or lower quality as compared to the same wine served in a classic wine glass.



Fig. 11.3 The New Covent Garden Soup Company carton. This Elopak package captures the associations with milk (which is sold in a similar container in the UK) of freshness. The image mold is consistent with the notion of product freshness (Meyers, 1981). © 2012 New Covent Garden Soup Company.

apparently say “Ahh, this is something like my grandma used to make” (Gladwell, 2005, p. 66). One particular successful example of using the associations that people have between product attributes and packaging/container shape is The New Covent Garden Soup Company’s brand cartons (see Figure 11.3). They convey the notion of freshness by switching from the traditional can format for soup and “hijacking” the associations that go in the typical UK consumer’s mind with the Tetrapak format (in which one normally thinks of fresh milk being sold). Here the opportunity exists for marketers to look for strong correlations that already exist in the marketplace between specific (identifiable) product shapes and high-quality product offerings. By “hijacking” the packaging or package shape (or image mold) that is normally used for a high-quality product, designers may be able to capitalize on these associations and hence improve the perceived product offering (see also Parise & Spence, 2012b).

As a cautionary note, though, one example of what not to do in this area comes from the decision by one major food company to pack its salsa in the packaging it already used for dog food. While such an approach certainly capitalized on the pre-existing availability of in-house packaging solutions (thus saving money when considered next to the alternative of introducing a new form/shape of packaging), it unfortunately captured all the wrong haptic/visual associations (at least amongst all of the salsa-eating dog-owners out there). Unsurprisingly, this product was not a great success, and was soon withdrawn. Thus, if one is going to change the design of one’s packaging, it should always be for a form of packaging that has the right connotations in the mind of the target consumers (think, for example, of the masculine form of the Listerine mouth wash container as compared to the more feminine shape of the Dove deodorant stick; see also Karana & Hekkert, 2010, for the association between a product’s shape and its meaning; and Krishna, Elder, & Caldara, 2010, for the association between touch and smell in the evaluation of products).

Such considerations may also help to explain why it has proved so difficult for marketers to shift wine consumers from the traditional wine bottle to the more practical (and possibly more environmentally friendly) cartons (while cartons may have associations with freshness, they do not, at least not for most consumers, have associations with a high-quality product). Screw-top bottles and plastic corks, while in many ways better (or at least more practical and/or easier to open; and what is more are often rated as tasting better in blind taste tests than traditional cork-stoppered bottles; see Goode, 2005) than the traditional cork also took a surprisingly long time to gain the acceptance of consumers.

Marketing research conducted on behalf of Coca-Cola reported that consumers overwhelmingly prefer the contour package over straight-walled generic bottles by a margin of 5-to-1 (Prince, 1994).⁶ This preference apparently translated into a substantial 25–66% volume growth in their contour market tests. Finally, while we are on the topic of the macrogeometric property of packaging shape, it is worth noting that Raghurir and Greenleaf (2006) have suggested that the shape of the packaging (in particular, with regard to the ratio of the sides of rectangular packages, and how closely they approximate the golden ratio; Green, 1995) can also influence the consumer's decision to purchasing (see also Yang & Raghurir, 2005).

Marketers have now begun to realize that changing the tactile attributes of a package can make them appeal to a specific gender or category of buyers more than to others. For example “Kraftpak,” an unbleached brown craft board, is often used by marketers for its rugged look; an additional value for many men's cosmetic products (<http://www.brandpackaging.com/Archives_Davinci?article=622> downloaded on October 22, 2012). Matthew Unger, purchasing group manager at Procter & Gamble suggests that a good design, in term of material, craftsmanship, and visual quality, is important in a successful package. Critically, however, he goes on to say that the way a package feels to the consumer, how “it speaks” through touch as well as vision, is the “moment of truth, the moment of choice” (<<http://www.brandpackaging.com/articles/see-me-smell-me-touch-me-special-effects-add-multi-sensory-allure>> downloaded on October 23, 2012). Along similar lines, Nipun Marwah, marketing manager for MeadWestvaco's Packaging Resources Group, suggests that “when you create a tactile feel, the consumer is more likely to pick it [the product] up. And once it is in the consumer's hand, the sale is that much closer” (see also Underhill, 1999; cf. Meyer, 2001).

Clearly, then, certain classes of products might benefit more from a change in the tactile sensations delivered by the containers/packaging in which they are stored than others. One might ask why it is that perfume bottles (now typically considered a luxury item) are mostly made of glass. This is not only related to the fact that glass seems to be better suited for retaining subtle essences, but also because of the way it feels when held in the hand. In fact, handling an elegant sculpted glass container provides the consumer with a sense of luxury (in part, due to the weight that glass gives) that other materials, such as plastic (even if cheaper to produce), simply cannot provide (e.g., Caldwell, & Flammia, 1991; see Frost, 2006; <http://www.brandchannel.com/features_effect.asp?pf_id=302>; downloaded on February 20, 2006).

There is a clear association between weight and quality in many product categories, where often (but not always) the heavier the product, the better the perceived quality (see Lindstrom,

⁶ Note that the Coca-Cola bottle was designed almost a century ago with the specific aim of satisfying the request of Benjamin Thomas—an American bottler—for a soft-drink container that could be identified by touch even in the dark!; <<http://www.martinlindstrom.com/pdf/articles/Smashing%20your%20brand.pdf>> downloaded on October 20, 2012; see also Prince, 1994).

2005; Piqueras-Fiszman & Spence, 2011). The results of recent well-controlled laboratory studies support the idea that changing the feel of a package can give rise to a change in people's attitude/experience of a given product. For example, Schifferstein (2009) presented the participants in one of his studies with several cups made of different materials (glass, ceramics, opaque plastic, translucent plastic, and melamine) that were either empty or filled with different drinks (hot tea or soda). The participants had to rate their drinking experience on the basis of a number of scales (such as good–bad, beautiful–ugly, etc.). The results demonstrated the fact that the experience of drinking from a cup was affected by how people experienced the cup (e.g., people reported enjoying drinking soda from a ceramic cup less than when drinking the soda from a plastic cup; see also Krishna & Morrin, 2008; see Chapter 14). Meanwhile, Gatti et al. (in press) recently demonstrated that people will rate the fragrance of a liquid soap as more intense if the weight of the packaging in which it is presented is increased.

In fact, even those companies who provide products/services that would, at first glance, seem to be “intangible” (and certainly do not usually come in a package) have started to experiment with the feel of their packaging (see Lewis & Street, 2003). How, one might ask, can financial products be made tangible? Well, the Danish Jyske bank came up with an innovative “tactile” solution: They made their financial products (e.g., loans, mortgages, etc.) more physical and tangible by putting them into boxes such as software boxes and DVD cases, so that customers could pick them up and read the brochures inside (see Stephens, 2008; <<http://www.streamingmedia.com/Articles/Editorial/Featured-Articles/Case-Study-Jyske-Bank-Serves-Espresso-Enterprise-Video-64976.aspx>> downloaded on October 23, 2012). An increasing number of companies are now engaging in innovative direct marketing designed to stimulate their potential customers' sense of touch (Street & Lewis, 2001).

It is important to note that the ease of opening packaging can also influence people's evaluation of a product. For example, a classic study on this phenomenon by McDaniel and Baker (1977) was conducted on 400 (primarily female) shoppers at two large supermarkets in the United States. The shoppers were given two bags of potato chips to try, one after the other (with the order of presentation carefully counterbalanced across consumers). Half of the potato chips were packaged in wax-coated paper bags, the rest in polyvinyl bags (an increasingly popular form of packaging at the time that the study was carried out). Despite the fact that the majority of the participants (87%) found the wax bags easier to open, the shoppers nevertheless rated the potato chips in the polyvinyl packs as being both significantly crisper and significantly tastier. What is more, subsequent blind tasting of the crisps from these two packets revealed there to be absolutely *no* difference in taste between them, thus showing that the effect of product packaging (and perhaps of ease of opening) was psychological rather than physical (i.e., in terms of the potato chips actually tasting different) in nature. Here it should also be noted that the shoppers in McDaniel and Baker's study rated the “taste” as being the most important product attribute for potato chips. Their results show, however, that despite what people say, other product and packaging cues can also play an important role in what customers would argue to be a primarily gustatory experience (at least when the actual differences in taste are minimal). Once again, the take-home message from this classic study is that one cannot rely on what a consumer says is the sensory cue driving their purchasing decisions (see also Chapter 9, for a discussion on this point). By contrast, more accurate and controlled studies (where the actual behavior rather than responses to a questionnaire are used), perhaps based on the affective ventriloquism effect suggested earlier, should provide more reliable data for marketers and product designers.

The research reviewed in this section has highlighted the importance of both the macrogeometric and microgeometric attributes of packaging in people's product evaluations and purchase

behaviors.⁷ Future research will need to concentrate on studying the tactile (e.g., texture, shape) as well as the visual aspects of packaging design that can affect the perception of the product contained within. That is, one might ask how the color and feel of a package interact in making a product more appealing to the costumer or even in enhancing the qualities of the product it contains (e.g., the taste for a particular food; see Krishna & Morrin, 2008; Schifferstein, 2009; Spence & Piqueras-Fiszman, 2012)? One obvious possibility here would be to have textures that reproduce the feel of the fruit or vegetable within (see Figure 11.1a). Given the research that has been conducted so far on this topic, we would expect that the use of packages having a feeling that is “congruent” with the taste/flavor, or more generally with the characteristics, of the product stored within should result in significantly more positive judgments regarding the product itself by customers (see also Overbeeke & Peters, 1991). For example, coating the container (i.e., bottle or can) in which a peach-flavored iced tea drink was presented might help to enhance the fruit flavor for those who consumed the product direct from the container.

11.3.5 Individual differences in the “need for touch”

Recent research suggests that there might also be important individual differences in the need for touch and in the extent to which tactile cues affect a customer’s evaluation of particular products (e.g., Citrin et al., 2003; Peck & Childers, 2003a, 2006; Peck & Wiggins Johnson, 2011; see also Cho & Workman, 2011; Workman, 2010, for the need for touch in those interested in fashion). For example, Citrin et al. reported that women appear to need tactile input significantly more than men when evaluating products. Even within a given gender, however, individual differences can also be found. Of course, age-related changes in sensitivity (as discussed elsewhere in this volume) are likely to give rise to substantial individual differences in the need for touch. Peck and Childers have demonstrated that people differ in terms of their “need for touch,” defined as “a preference for the extraction and utilization of information obtained through the haptic system” (2003a, p. 431).

The 12-item questionnaire developed by Peck and Childers (2003a, b) in order to assess an individual’s need for touch is shown in Table 11.2. Six of the questionnaire items were designed to capture an individual’s general liking for haptic input from products (what they call the *autotelic* dimension, and meaning those who touch products for the sheer sensory pleasure of the experience, think only of the pleasure of rubbing a cashmere sweater between the fingertips and thumb) by getting people to rate the extent to which they agree with statements such as “touching products can be fun” and “when browsing in stores, I like to touch lots of products.” The other six questionnaire items were chosen to be more relevant to specific product purchases (Peck and Childers labeled this the *instrumental* dimension), and include participants rating the extent to which they agree with statements such as “the only way to make sure a product is worth buying is to actually touch it” (i.e., those who gather information about a product in order to help then come to a decision about the product). Peck and Childers (2003a, b) reported that people with a greater need for touch were more confident in their product judgments (e.g., regarding a sweater) when allowed to evaluate it by touch but they are more frustrated when not permitted to touch them. Here, referring back to our earlier discussion of Internet-based shopping behaviors, one might think that those individuals who score higher in terms of their need for touch would be less likely to make Internet purchases of items having experience attributes such as clothes than individuals scoring lower on the need for touch scale.

Subsequent research by Krishna and Morrin (2008) has demonstrated that individual differences in the need for touch, as picked up by the autotelic dimension of Peck and Childers

⁷ A Ben & Jerry’s ice cream advertisement made the claim that the product is “99% pleasure. The rest is the carton.” We would argue that the empirical evidence suggests otherwise.

Table 11.2 The items composing Peck and Childers (2003a, b) "Need for Touch" scale. Scale descriptors ranged from -3 (strongly disagree) to +3 (strongly agree). A = autotelic scale item; I = instrumental scale item. See main text for details.

The "Need for Touch" scale items

1. When walking through stores, I can't help touching all kinds of products. (A)
2. Touching products can be fun. (A)
3. I place more trust in products that can be touched before purchase. (I)
4. I feel more comfortable purchasing a product after physically examining it. (I)
5. When browsing in stores, it is important for me to handle all kinds of products. (A)
6. If I can't touch a product in the store, I am reluctant to purchase the product. (I)
7. I like to touch products even if I have no intention of buying them. (A)
8. I feel more confident making a purchase after touching a product. (I)
9. When browsing in stores, I like to touch lots of products. (A)
10. The only way to make sure a product is worth buying is to actually touch it. (I)
11. There are many products that I would only buy if I could handle them before purchase. (I)
12. I find myself touching all kinds of products in stores. (A)

(2003a) questionnaire, can affect people's evaluation of a drink served in a plastic cup (see also Chapter 14). In their between-participants study, conducted in a university cafeteria, 180 people were asked to evaluate a single sample of a drink (water mixed with Sprite) that they tasted through a straw. Half of the participants touched the flimsy cup with their hand before evaluating the drink, the others did not. The results showed that those participants who scored higher in their need for touch (based on a median split) were less affected in their evaluation of the drink by irrelevant haptic cues (related to the feeling of the firmness of the cup in which the water was served) than were participants who scored lower on the need for touch (see Figure 11.4). These

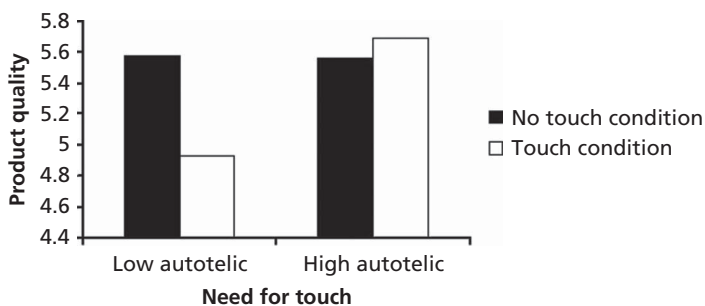


Fig. 11.4 Results of Krishna and Morrin's (2008, experiment 1) study of the effect of individual differences in the need for touch, as assessed by Peck and Childers (2003a, b) "Need for Touch" scale, on people's evaluation of a beverage (product quality ratings were given on a 9-point scale with 1 anchored as "Very low" and 9 as "Very high") as a function of whether or not they were allowed to touch the flimsy plastic cup in which it was served. Data from Krishna, A. and Morrin, M., Does touch affect taste? The perceptual transfer of product container haptic cues, *Journal of Consumer Research*, 34, pp. 807–818, table 1, 2008.

findings suggest that changes in the haptic qualities of a product's packaging might have different effects on different customers as a function of their general liking for haptic input. In terms of the marketing implications for targeting the sensory (or sensual) shopper, we would expect that an increase of tactile content in a given product, or in its packaging, should be more effective in affecting the purchase behavior of higher need for touch individuals than for lower need for touch individuals. Moreover, one might also expect this effect to be larger when the tactile content added to the product is "relevant and informative" regarding the product itself. By contrast, the addition of irrelevant cues should only affect people with a lower need for touch.

11.4 Tactile brands that aren't and others that might be

One thing that is crucial to realize, but which is frequently overlooked when talking about tactile branding, is that just because a brand, or product, has a distinctive feel, or shape, it doesn't mean that that feel or shape will necessarily be distinctive, or dominant, in the mind of the consumer. Take, for example, the iconic Coca-Cola bottle: In his influential book *Brand Sense*, Lindstrom (2005) argues that this iconic example of packaging provides an excellent example of just how successful tactile branding can be. Even though the limited research suggests that people are surprisingly good at recognizing everyday objects on the basis of touch/haptic cues alone (i.e., in the absence of vision; see Bader & Phillips, 1999; Klatzky et al., 1985; see also Chapter 5), other laboratory research has demonstrated that things are not quite so simple. So, for example, given that people nearly always look at products before picking them up, and given that vision dominates over touch in the majority of situations (of intersensory conflict), especially when people have to evaluate the shape of an object (Ernst & Banks, 2002; Rock & Victor, 1964; see Spence & Gallace, 2008, for a review), one might reasonably assume that it is the "sight" of the uniquely shaped bottle that is key to the brand image, rather than its unique shape. Perhaps in recognition of this fact, a silhouetted image of the signature bottle shape is often printed on the side of their cans (see Prince, 1994).

Of course, this is not to say that tactile brands cannot exist. In fact, tactile cues often dominate over visual cues when judging attributes such as an object's temperature (e.g., Bushnell, Shaw, & Strauss, 1985; see also Schifferstein, 2009) or its fine surface texture (Guest, Catmur, Lloyd, & Spence, 2002; Spence & Gallace, 2008). As a general rule-of-thumb, it should be noted that visual cues tend to dominate over touch/haptics when people judge the macrostructural properties of an object/product (i.e., such as its size/shape), whereas tactile cues more often dominate people's perception of the microstructural features of a product, such as its texture (Guest & Spence, 2003a; Spence & Gallace, 2008). It should also be noted here that visual research has shown that previous exposure (even when subliminal) to stimuli can increase people's subsequent preference for those stimuli (a phenomenon known as the "mere exposure effect"; e.g., Bornstein & d'Agostino, 1992; Harrison, 1977; Kunst-Wilson & Zajonc, 1980; Monahan, Murphy, & Zajonc, 2000; Shevrin, Smith, & Fritzler, 1971; Zajonc, 1968, 1980). A similar phenomenon has now been reported in the tactile modality as well, and also crossmodally between vision and touch (e.g., Jakesch & Carbon, 2012; Suzuki & Gyoba, 2008).

For instance, research by Suzuki and Gyoba (2008) has demonstrated that people prefer the feel of objects that they have previously inspected visually. Furthermore, Jakesch and Carbon (2012), have recently reported that the mere exposure effect for haptically explored objects is more pronounced in those participants with a high "need for touch" (see Peck & Childers, 2003a; see also

Chapter 12). Somewhat surprisingly, however, touching the objects did not modulate subsequent visual-only preference judgments.⁸

Given that the objects used by Suzuki and Gyoba (2008) were all novel and meaningless, one might expect that somewhat different results would have been obtained had actual products (where a positive emotion can be elicited by the recognition of a well-known tactile feel) been used. Moreover, one might even expect different results when using objects that remains in our hands for longer time when used (e.g., a steering wheel, a tennis racket, a fork, a toothbrush, a razor) as compared to objects that are touched very briefly (and therefore are probably forgotten more rapidly) when we interact with them (e.g., a door handle, a key, or even food). Nevertheless, Suzuki and Gyoba's results do at least provide some evidence that people may like a product more if they happen to have held it in their hand(s) previously (see also Jakesch & Carbon, 2012). Results such as these therefore provide support for Heslin and Alper's (1983, p. 63) suggestion that touching causes liking. The challenge for sensory marketers then is to find ways to increase the probability that a potential customer picks up specific products (e.g., Klatzky & Peck, 2012).

One recommendation that falls directly out of this research is that anything that can be done to increase a consumer's exposure to the tactile attributes of a product may ultimately have beneficial consequences on their product evaluation and purchase behavior. That said, remember that all of Suzuki and Gyoba's (2008) stimuli had the same surface texture, and consequently, their results can only speak to the existence of a mere exposure effect for the *macrostructural* property of object shape. Similarly, in Jakesch and Carbon's (2012) study of haptic mere exposure, the researchers failed to systematically vary the microstructural properties of their stimuli, even if more complex 3D objects were used than in previous research. Therefore, further empirical research will be needed in order to determine whether the tactile mere exposure effect also extends to other haptically perceived product attributes, such as, for example, surface texture (i.e., to the microstructural object attributes), pliability etc. It is also worth noting here that, just as for visual stimuli (e.g., Howes, 2005; Schacter, 1987), the tactile qualities of a given product might be *implicitly* associated with a specific brand (cf. Ballesteros & Reales, 2004). This latter claim, together with the existence of a mere exposure effect for previously touched stimuli, might lead to the suggestion that tactile brands might exist regardless of our explicit association of a certain brand with a particular tactile feeling (attribute).

Changing the tactile attributes of a product might also help to differentiate one's brand from the rest of the field. For example, one study reported in *Digital Photo Magazine* revealed that people think that most digital cameras look pretty much the same, that is, the people tested in the study were unable to differentiate the brands based on visual cues alone (see "Concorso Coolproject ("Coolproject competition")," 2009). Thus, changing the macrogeometric and/or geometric tactile attributes of a camera (but note that the same line of thinking can be extended to any handheld electronic device), could provide an effective means of product/brand differentiation (see Figure 11.3, for a possible example of brand differentiation by means of tactile attributes). As the results of the studies described in this section show, scientific endeavor doesn't always confirm marketers'

⁸ In order to interpret this asymmetrical crossmodal transfer effect, the authors suggested that their results were likely caused by the fact that the participants in their study were blindfolded while exploring the stimuli. That is, when people cannot see anything they might become more vigilant for any possible signs of danger and thus more careful about what they touch. This reaction could have affected the participants' motivational states in terms of their attempting to avoid negative events.

intuitions about products and why they are successful. In fact, the majority of product design innovations, be they related to the tactile, visual, olfactory, or auditory attributes of a product, have typically been based on the intuition of the product designer/engineering or on the demands of the marketing executive (Hine, 1995; though see Nagamachi, 1995; Schütte et al., 2008). While many such decisions have ultimately led to hugely successful products and marketing campaigns, it is important to note that the majority of all new products (estimated to be around 70–80% by market research performed in 1997 by Linton, Matysiak, & Wilkes Inc.; Underhill, 1999, p. 163; and up to 95% by others; e.g., Nobel 2011; Schneider & Hall, 2011; see also Robinson, 1998, p. 134; Zaltman, 2003, p. 3) fail. This has led many companies to wonder whether there might not be a better way to go about product design, development, and marketing. It is with this backdrop in mind that more and more companies have now started turning to the rapidly growing field of cognitive neuroscience in order to search for inspiration regarding the principles that should govern their future product development and marketing decisions (Ariely & Berns, 2010).

The problem in terms of relying on one's intuitions can be seen with reference to an article by Gentile, Spiller, and Noci (2007) published a few years ago in the *European Management Journal*. They asked 200 people aged between 16 and 55 years to rate the sensory modality that was most important for a range of different products. Using this data, they produced a table listing the most important modality for various products. So, for example, they suggest that Snapple soft drinks and Pringles potato chips are all about the taste (here agreeing with the customers questioned by McDaniel & Baker, 1977, discussed earlier), that Harley-Davidson motorcycles are all about the sight, while the iPod is all about the sound. We would, however, like to argue that many of their claims are simply wrong. For there is evidence to suggest that our perception of Pringles may have as much to do with the sound that they make when we bite into them (see Zampini & Spence, 2004), while a key component of the sensory appeal of owning a Harley-Davidson comes from the distinctive sound that its exhaust makes (see Sapherstein, 1998; Spence & Zampini, 2006). Similarly, much of the success of Snapple in recent years can perhaps be put down to the unique sound that is elicited by opening one of their soft drinks bottles (Byron, 2012), and much of the appeal of iPod comes from the way it feels in the hand (see earlier; Johnson, 2007); In fact, the sound quality of the iPod may well be indistinguishable to the average ear from that of other portable music players (e.g., see <http://reviews.cnet.com/4520-11297_7-6510133-2.html>, downloaded on July 20, 2009). The data summarized in this section would therefore appear to suggest (once again) that marketers should not base their decision (regarding how to enhance the sensory attributes of a product successfully) solely on people's "explicit" opinion regarding a product, but also on the results of the laboratory-based cognitive and neuroscientific research related to the way in which our senses interact in eliciting a response to a given stimulus. That is, from a marketer's perspective, what a participant says about a given product should be much less important than what kind of product attributes activates a particular behavior (e.g., buying the product), or a particular perception or emotion in the customer's mind (e.g., Hekkert & McDonagh, 2003; McDonagh, Hekkert, Erp, & Guy, 2004; Norman, 2002).

The rapid development of studies investigating the cognitive and neural mechanisms underlying the integration of information from different sensory modalities (i.e., what is known as the study of multisensory processing; see Spence, 2002a, 2010a) is now revealing a number of insights and rules that govern multisensory perception (e.g., of objects, products, or their packaging). This research is helping to demonstrate just how much what one feels when one interacts with a product or surface is determined not only by what is going on at the skin surface, but also by what a consumer happens to be smelling (e.g., Churchill, Meyners, Griffiths, & Bailey, 2009; Demattè et al., 2006; Laird, 1932), hearing (Gomez-Ramirez, Lee, Dammann, Craig, Hsiao, & Yoshioka,

2009; Spence & Zampini, 2006; Zampini, Guest, & Spence, 2003; see Spence, 2008, 2009, 2011a; Spence & Zampini, 2006, for reviews), and seeing (see Gallace & Spence, 2008b, for a review). We believe that the cognitive neuroscience approach holds the promise of delivering on design principles for stimulating a consumer's senses (all of them) more effectively, using knowledge and understanding that stretches across product categories (Spence, 2002b).

11.5 The cognitive neuroscientific approach to tactile perception

The rapid growth of awareness regarding the importance of the tactile (and multisensory) aspects of product design has come about not only because of recent developments in technology, but also (and probably even more importantly) because of our growing understanding of the mechanisms underlying tactile perception in humans (e.g., see the first few chapters in this book). Indeed, producers are now learning how to develop a product's tactile attributes so that the design optimally delivers a specific kind of perceptual experience to the consumer. Over the last few years, there has been a growth of interest, for example, in the feeling of *naturalness* (e.g., Jacobs, Renken, & Cornelissen, 2012; Overvliet & Soto-Faraco, 2008; Spence, 2007a, b; see Whitaker, Simoes-Franklin, & Newell, 2008, for the contribution of vision and touch to the perception of naturalness). That is, advances in our neuroscientific knowledge of, as well as the cognitive foundations underpinning, tactile perception, will hopefully soon allow designers to create products that maximize the stimulation of specific classes of sensory receptors in the skin (e.g., such as the CT afferents related to tactile pleasure; Löken, Wessberg, Morrison, McGlone, & Olausson, 2009; Olausson et al., 2008; see also Chapter 2), and hence elicit specific sensations, such as the feeling of naturalness, in the mind of the customer.

Preliminary work illustrating this approach comes from Zampini et al. (2006). They looked at the design of the applicator of stick deodorants. Participants were given a number of different stick deodorants to rub across their skin (see Figure 11.5), and they had to rate the roughness/

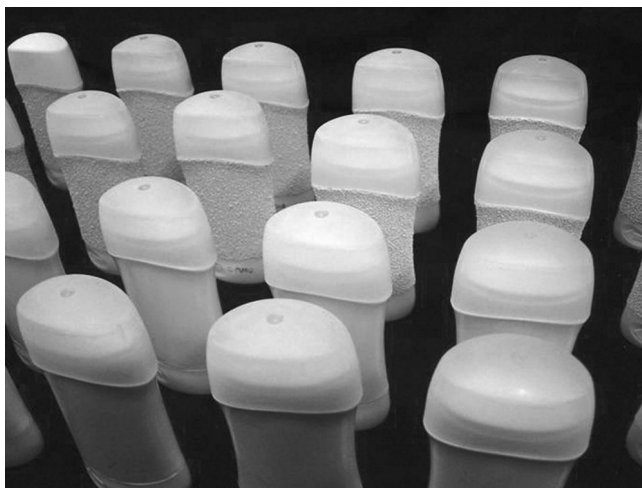


Fig. 11.5 A number of the differently textured deodorant sticks used in Zampini et al.'s (2006) study of the feel of deodorant sticks. Reprinted from *Neuroscience Letters*, **400** (3), Massimiliano Zampini, Sara Mawhinney, and Charles Spence, Tactile perception of the roughness of the end of a tool: What role does tool handle roughness play?, pp. 235–9, Copyright (2006), with permission from Elsevier.

smoothness of the tip of the deodorant while trying to ignore the feel of the handle of the deodorant stick. The roughness of the deodorant stick's applicator handle was found to modulate participants' judgments concerning the roughness of the cap of the deodorant. These results demonstrate that people cannot always completely ignore tactile sensations at one location (the hand) when simultaneously trying to attend/respond to stimuli presented at another body site. Cognitive neuroscience research has further revealed that hand-held tools and objects can be rapidly incorporated into the body schema (e.g., Carlson, Alvarez, Wu, & Verstraten, 2010; see Holmes & Spence, 2006, for a review; see also Chapter 8), and can even lead to temporary changes in the body schema after the tool or object has been put down (Cardinali, Frassinetti, Brozzoli, Urquizar, Roy, & Farnè, 2009); that is, the deodorant stick may briefly be integrated into a person's body image when he/she uses it. Results such as those reported by Zampini and his colleagues may therefore have important consequences for the development of packages and containers for those products that are predicted to come into contact with the consumer's skin. Indeed, given Zampini et al.'s findings, one might reasonably think that the wrong choice of a lipstick container by a make-up company might negatively affect the sensation of the product on a customer's lips (especially since the lips is the part of the skin surface that has the highest tactile sensitivity in humans; e.g., Weinstein, 1968), and consequently also its success in the marketplace. One might also think about introducing temperature contrasts between the body of a drinks container (held in the hand) and the opening that comes directly into contact with a customer's lips.

While cognitive neuroscience researchers have distinguished between the contributions of several different relatively independent submodalities to the perception of touch (e.g., such as pressure, temperature, vibration, pleasure, and pain; Sonneveld & Schifferstein, 2008), what is remarkable is how these various sensations are always subjectively grouped into a single *Gestalt* percept of an individual object (albeit an object with multiple distinguishable features) manipulated in the hand (see Chapter 3). That is, the final perception of a product, just as of any other stimulus, is not necessarily determined by the mere sum of its individual sensory attributes. Indeed, in Chapter 2, we saw how many of the most salient attributes of our tactile experience represent not the activity of a single class of receptors in the skin, but instead the synergistic activation of different combinations of receptors in what are known as "*touch blends*" (see Bentley, 1900; Katz, 1925/1989). Similarly, the feeling of "naturalness" is also likely to reflect a multisensory touch blend.

Psychophysicists have spent a lot of time trying to determine what exactly are the fundamental dimensions underlying our tactile perception of surface texture. So, for example, Hollins, Faldowski, Rao, and Young (1993) suggested three dimensions, namely rough/smooth, soft/hard, and a third dimension related to elasticity (or springiness of a surface). Meanwhile, a few years later, Picard, Dacremont, Valentin, and Giboreau (2003) came up with four distinct dimensions to classify tactile materials, namely soft/harsh, thin/thick, relief, and hardness. However, the number and identity of the dimensions one comes up with is, to some extent, determined by the nature of the materials/surfaces that participants in these studies are given to evaluate (see also Giboreau, Navarra, Faye, & Dumortier, 2001). Moreover, the lack of a widely accepted language of touch may in the end be important as Randall Frost, author of *The Globalization of Trade*, has argued: "touch is a form of communication that doesn't use words and therefore isn't limited by the language barrier" (see Johnson, 2007).

There is currently a great deal of interest in trying to understand what drives the feeling of naturalness, given current trends for natural and/or ecologically friendly products. Understanding the way in which our brain combines information regarding different aspects of tactile perception (and from different sensory modalities) in order to give rise to the perception of a particular quality of a stimulus, might offer important opportunities for product designers. Marketers also need

to be aware of which characteristics of a product (at the macro- and/or microgeometric level) need to be modulated (and in what proportion) in order for it to be perceived as desired (and/or lead to the wanted behavior). Another important contribution from the cognitive neuroscience approach might also come from the mathematical modeling of multisensory interactions in hedonic judgments (see Chapter 12). One might even consider whether the MLE approach (see section 11.2.2) to multisensory integration could be brought to bear on the question of which combination of sensory cues can best convey the feeling of naturalness in a product and its packaging.

11.5.1 Cracking the brain's code for marketing purposes?

Over the last few years, neuroscience research has begun to address questions related to the patterns of brain activation that might correspond to a positive/negative evaluation of a given product (e.g., by using brain-imaging techniques in the laboratory or by means of portable electroencephalography (EEG) recorders worn by people while shopping; e.g., Lewis & Brigder, 2005; Paiva et al., 2007). This kind of research comes under the heading of “neuromarketing” or “consumer neuroscience” (see Ariely & Berns, 2010; Babiloni, 2012; Lewis & Brigder, 2005; Plassmann, Ramsøy, & Milosavljevic, 2012; Vecchiato, Astolfi, De Vico Fallani, Toppi, Aloise, Bez, et al., 2011). The strategy promises to enable researchers to understand which product attributes are more attractive for a potential customer by bypassing his/her explicit evaluation of it (as obtained with classic questionnaire procedures; see also Lindstrom, 2008; McClure, Li, Tomlin, Cypert, Montague, & Montague, 2004; Miles, 2009).

A recent example of research in this field comes from a study by Reimann, Castaño, Zaichkowsky, and Bechara (2012) where the authors used neuroimaging in order to understand the brain correlates of people's choices for novel or familiar brands. They had participants choose or reject (by pressing a key) a given logo presented on a screen while lying in a fMRI scanner. Half of the logos were explicitly created for the experiment by a graphic designer while the other half consisted of logos that the participant already knew. The results demonstrated that the choice of novel brands (compared to the choice of familiar brands) was preceded by increased activation of both the cingulate gyrus (a brain area involved in reward-based decision making and in the integration of bodily and attentional information) and the ventromedial prefrontal cortex (an executive control area). Taken together these results clearly suggest the importance of the involvement of areas of the brain responsible for the processing, storage, and control of attention (as well as for defining their emotional valence) regarding the specific attributes of products/brands that are important in driving shopping behavior.

Although progress has been made toward understanding the neural correlates of tactile perception and tactile object recognition/representation (e.g., see Chapters 3 and 4), we would like to argue that the neuroimaging approach to the design of products that appeal to the sense of touch (as well as to the other senses) is still not practical. Further research on this topic will be necessary in order to improve our understanding of people's use of tactile information in product evaluation. Indeed, the constraints currently associated with neuroimaging need to be borne in mind: For example, the currently popular technique of fMRI requires participants to lie in a narrow (some would say claustrophobic) tube and keep their head absolutely still. Such constraints obviously make it more difficult to engage in any kind of naturalistic haptic manipulation of a product/package. The development of the new range of vertical bore scanners (that allow the participant to sit upright) will no doubt help. At the moment, though, the use of portable electrophysiological recording devices (such as offered by measuring event-related brain potentials; ERPs) seems a more viable solution.

An increasing number of practitioners appear to believe that the use of neuroimaging will constitute an important basis for the design of more appealing products in the future. For example, if marketers believe that a given product will be purchased on the basis of factors that are more emotional than rational, say, then they should understand which characteristics of the surface of their product have the strongest effect in eliciting the activation of those areas of the brain responsible for the emotional processing of the stimuli. As far as “market segmentation” is concerned, it is worth noting that elderly people use different functional brain networks than younger people when carrying out the same cognitive task. This presumably reflects a compensation for reduced efficiency of certain of the brain areas typically used by young adults in the same tasks (e.g., Cabeza, 2001). Marketers should therefore not only consider the importance that different brain areas have in driving particular behaviors (such as, for example, remembering the name or feel of a given product) but also that different mechanisms (and different brain networks) can be activated when performing the same task in different groups of people. Gaining a better understanding of the neural circuits activated in a given population when performing a given task might provide important cues for designing products (or marketing campaigns) that are better suited for certain people rather than others.

11.5.2 Touch and pleasure

If one wants to understand the mechanisms underlying the effect of touch on people’s shopping behaviors, cognitive and neuroscientific studies addressing the relationship between touch and pleasure are going to be particularly relevant (see Bonapace, 2002; Hekkert, 2006; see Hofmeester, Kemp, & Blankendaal, 1996, for a discussion of the importance of pleasure and sensuality in product design). Over the last few years, researchers have started to address questions such as: Why do tactile sensations sometimes have such a profound effect on people’s behavior? And under what conditions can tactile stimuli activate the neural networks responsible for the perception of pleasure in the brain (see also Chapter 13)? As seen in Chapter 2, much of the excitement over the last few years has come from the discovery that a class of receptors in the human hairy skin seems to code for pleasant touch (Francis, Rolls, Bowtell, McGlone, O’Doherty, Browning, Clare, & Smith, 1999). Clearly, from the point of view of the possible application of such findings, this represents something of a challenge given that so much of our product interactions take place with the (non-hairy or glabrous skin of the) hands, and the fact that tactile stimulation at the hand can dominate that at other body sites (e.g., von Békésy, 1963; cf. Zampini et al., 2006).

11.6 Advertising a product’s tactile qualities

An important problem for those companies whose products have desirable tactile/haptic properties is that the typical forms of advertising (print media, the radio, television, and lately Internet campaigns) can only deliver information to the eyes and/or ears of the potential customer (e.g., Johnson, 2007; Lucas & Birtt, 1950; Robinson, 1998, p. 179). The relevant question here then becomes one of how a company can appeal to/stimulate a potential customer’s sense of touch? It turns out that there are actually a number of solutions. One possibility involves the use of *touch-related adjectives* in advertising or naming a given product (or putting the emphasis on the tactile attributes of the products on the packaging itself; see Sheldon & Arens, 1932). This is the case for many products, from fabric conditioners to beauty products and accessories, comprising even everyday household items and beverages: Take Nivea’s new “Irresistibly Smooth” and “Light Touch” body lotions, for example.

A second, and somewhat more subtle approach may be to use synesthetic⁹ advertising in order to stimulate a sense that cannot be stimulated directly using more indirect means (see Nelson & Hitchon, 1995, 1999; Spence, 2012d; Vickers & Spence, 2007). So, for example, take the following examples: The Lou Lou perfume brand used the synesthetic copy “When the perfume becomes a caress. . .”; Purex Toss ‘N Soft fabric softener used the following “Softness you can smell”; and for Skin Musk cologne the strap line was “If warmth had a scent, it would be Skin.” In all of these cases, the advertising tries to indirectly stimulate (e.g., through people’s imagination) tactile sensations by means of synesthetic associations. If anything, this trend toward sensory blending is predicted to increase in the coming years (see Meehan, Samuel, & Abrahamson, 1998; and Table 11.1).

Many designers have also made frequent attempts to evoke the sense of touch by means of visual content, whenever relevant to the product to be advertised. Different kinds of products, among which foods, drinks, fabric conditioners, furniture, moisturizing creams, and clothing, all seem to be well suited to being accompanied by images that are specifically selected to evoke tactile sensations in the mind of the potential buyers. So, for example, Procter & Gamble for their “Fairy Liquid” fabric conditioner advertising campaign made extensive use of images reminding the customer of soft sensations (such a fluffy teddy bear, a baby falling on his backside, green grass etc.; see Sheldon & Arens, 1932, for earlier examples). Similarly, the 2012 Lenor advert presents images of people lying on a comfortable bed. It is worth mentioning here that such a synesthetic approach to tactile marketing might find a neuroscientific foundation in the discovery that areas of the brain responsible for tactile processing such as S1 are also activated when people see another person being touched (e.g., Banissy & Ward, 2007; Banissy, Cohen Kadosh, Maus, Walsh, & Ward, 2009).

Another promising approach that has increasingly been used by marketing campaigns in the last few years is to send potential purchasers of high-end products mail-shots that incorporate the innovative uses of tactile graphics and tactile design second (see Street & Lewis, 2001, for a number of excellent examples; see also Stephens, 2008). Note here also the potential benefits in terms of the mere exposure effect (see section 11.4). A final successful approach to the advertising of the tactile attributes of products has come from the modification of the auditory cues of a product in an advertisement. This technique can be used to suggest to the customer what the tactile qualities of the product will be like. For instance, the sound of the crack of the chocolate on a Magnum ice-cream bar tells the person who is eating it (and anyone else who can hear the sound) about the tactile attributes of the chocolate coating. Boosting the sound of the chocolate cracking in a radio or TV advertisement can then be used to enhance a viewer’s perception of the texture of the chocolate coating (see Spence, 2010c, 2011e; Spence & Zampini, 2006). Some years ago, Gillette used the sound of the edge of a credit card being drawn across a person’s cheek to highlight the smoothness of the feel of the skin resulting from the use of their shaving products (see Lederman, 1979). Interestingly, neuroimaging research by Kitagawa and colleagues (see Kitagawa & Spence, 2006) has demonstrated that replaying the realistic sound of a brush being stroked against the ears can elicit activity in the somatosensory parts of the brain (despite the fact that no tactile

⁹ From the word “synesthesia,” describing a phenomenon in which stimulation in a given sensory modality automatically/involuntarily leads to an additional sensory experience (often in a second sensory modality; e.g., Baron-Cohen & Harrison, 1997). Note that synesthetic correspondences have also been demonstrated in the neurologically normal (e.g., Gallace & Spence, 2006; Parise & Spence, 2012a; though see Spence, 2011d).

stimulation was provided). Thus, when thinking about advertising the tactile attributes of products, it is important to consider how best to get them across using the available auditory and visual modes of communication. The key point here is that the inability to directly stimulate the consumer's skin does not mean that advertising cannot reach out to touch the consumer (using their other senses). The strategies highlighted in this section can be used by companies to help appeal to the sense of touch by means of the standard visual and audiovisual media.

11.7 Current challenges for tactile marketing

11.7.1 Tactile marketing for the graying population

An important challenge for many companies comes from the ongoing changes in population demographics. In particular, how to deal with the rapidly growing aging population. It has been estimated that by the year 2025 there will be more than a billion people over the age of 60 (USA Senate Special Committee on Aging, 1985–1986). The problem here is that as people age, their senses will start their inevitable decline (both centrally, i.e., in the brain itself, and at the periphery, i.e., at the skin surface; e.g., Lin, Hsieh, Chao, Chang, & Hsieh, 2005; Nusbaum, 1999). While the decline of visual and auditory sensitivity in the elderly has, to a large extent, been ameliorated by the provision of sensory prostheses, such as glasses and hearing aids, there is little that can be done to overcome the loss of tactile, olfactory, and gustatory sensitivity that is now adversely affecting the functioning of a growing section of the population (see Chapter 9 for a discussion of this point). It is worth noting at this point that “tactile acuity” (i.e., a measure of a person's ability to discriminate two stimuli presented close together as separate) declines in a more or less linear manner with increasing age (i.e., the older the person, the larger the separation needed between two stimuli on the skin in order for them to be perceived as distinct; e.g., Stevens, 1992). This kind of sensory decline is especially likely to affect people's perception of the microgeometric properties of tactile stimuli (such as their awareness of the particular texture of a product surface or of its packaging). Given that touch provides an important means of developing an emotional, or affective, connection with a product (e.g., Schifferstein & Hekkert, 2008; Sonneveld & Schifferstein, 2008), many companies are currently struggling with the question of how exactly to ensure that their products remain usable by, as well as appealing to, the touch of the elderly customer. Interestingly, the emerging neuroscience evidence suggests that the elderly may sometimes rely more on multisensory integration than younger people in order to make-up for the loss of sensitivity in each of the individual senses (Laurienti, Burdette, Maldjian, & Wallace, 2006; see also Bremner et al., 2012).

According to the Mature Marketing Group, the over-50s own 75% of America's financial assets; meanwhile, Age Concern's LifeForce estimate that only 25% of the over-50s in the UK prefer saving to spending. This raises a number of challenges for companies as they struggle to ensure that their products are haptically appropriate, and easy to use, for this cash-rich “graying” section of the population (see also “The silver dollar,” 2008). It is important to note here that the elderly are not only affected by sensory decline, their higher-order cognitive abilities such as memory, problem solving, and attention also show signs of decline as well. Therefore, when thinking about product design for the older population these factors also need to be considered. As far as this point is concerned, one might think that tactile feelings might actually help to overcome these age-related cognitive limitations. That is, given that tactile information has been shown to exert strong effects on people's behavior, regardless of their awareness of the actual sensations that have been presented (e.g., Crusco & Wetzel, 1984; see also Gallace & Spence, 2008a), using

tactile signature feels in order to help elderly people choose (or implicitly recognize) a given product, might result in important advantages for the marketing industry. The ongoing change in population demographics has actually led to a growing movement calling for a more “inclusive” approach to design (e.g., Pirkle, 1994).

11.7.2 Directions for future research

One area that seems bound to grow is the development of “signature feels” associated with the packaging of a brand. There has been a long history of companies developing and trade-marking signature colors, or visual designs (see Howes, 2005; Solomon et al., 1999), and, more recently, trade-marking product sound (Lindstrom, 2005; Spence & Zampini, 2006; Treasure, 2007). It would seem only natural, then, as packaging and coating technologies develop, for companies to consider the possibility of trade-marking a brand’s “signature feel,” and beyond that, of trying to protect the multisensory Gestalt of sensory attributes, given the multisensory nature of our overall product experience (see Bloch, 1995; Schifferstein & Spence, 2008). Indeed, as Howes (2005) points out, pack feel and shape constitute crucial aspects of experiential branding.

One of the most important challenges for innovative companies will therefore be to answer the following questions: What does our brand feel like to the consumer’s touch? What are the emotional and cognitive contents that we want our brand/product to communicate via the sense of touch? Once the message to-be-communicated by touch has been defined, the challenge becomes one of choosing those tactile sensations that are best suited to delivering that message (e.g., Smets & Overbeeke, 1995). Unfortunately, this step is further complicated by the fact that a proper “lexicon of touch” is only now starting to be developed by researchers, and has a long way to go before it is shared amongst not-experts (e.g., Guest et al. 2011; see also Philippe, Schacher, Adolphe, & Dacremont, 2003; Spence & Gallace, 2008; Johnson, 2007; Stadtlander & Murdoch, 2000). That is, tactile sensations are not as easily labeled as visual sensations (see Sonneveldt & Schifferstein, 2008). Moreover, as seen in previous chapters of this book, not as much is currently known about the way in which our brain analyzes, recognizes, and stores tactile information (as, for example, is known about the mechanisms of visual information processing; see Chapters 4–6). Further research in the fields of experimental psychology and cognitive neuroscience may certainly be of great help here. Finally, once a particular tactile feeling has been shown to be effective in terms of representing the brand or message, it needs to be translated into a suitable physical format (i.e., a tactile texture and/or shape). This latter step can certainly benefit from the advances that the last few years have witnessed in the development of new materials and coating technologies (e.g., Lindstrom, 2005). More research is also urgently needed in more realistic consumer settings.

Another area of possible development to further the use of touch in marketing is related to the question of whether the tactile attributes of a particular product and/or its packaging can be engineered to enhance the purchasing impulse (Robinson, 1998, p. 204; Rook, 1987; see also Schoormans & Robben, 1997). This might be achieved by one of two different means: (1) The design of a particular shape that when on display “invites” potential buyers to pick it up and hold it in their hands (note indeed that it is a commonly held belief by marketers that people are more likely to buy something if they can be induced to pick it up off of the shelves; see Peck & Childers, 2006)¹⁰; (2) The design of a packaging that when touched elicits a pleasurable experience, or at

¹⁰ This might be related to the concept of “product affordance,” where the term “affordance” was defined by the perceptual psychologist J. J. Gibson (1977) as the qualities of a given object that suggest the possibility of interaction relative to the ability of an actor (person or animal) to interact.

least an experience that is compatible with the characteristics that a potential buyer would like to find in a given product (e.g., softness for a beauty care product or firmness for a tool). There may also be scope to develop products/packaging that capture a customer's attention because the feel of the product is noticeably different from what is expected on the basis of the product's visual features (Schifferstein & Spence, 2008).

The second author of this book still remembers the time, several years ago now, that he first picked up the envelope in which the tasting menu at The Fat Duck restaurant had been placed in the middle of the table. It looked to have the texture of a regular vellum envelope than a traditional envelope. However, there was surprise (shock even) when actually touched; the texture of the envelope actually felt more like animal skin instead. Using multisensory incongruence to capture customer attention should, however, only be used with caution in the area of multisensory product design (see Ludden, Hekkert, & Schifferstein, 2008; Ludden & Schifferstein, 2007; Piqueras-Fiszman & Spence, 2012b; Schifferstein & Spence, 2008). In particular, it may only be appropriate for products/packaging where the norm is clear (otherwise what was intended to elicit surprise/attentional-capture might instead end up looking simply like a case of poor design).

An alternative approach to the engineering of specific product qualities/attributes that deserves a mention here comes from the Kansei Engineering approach (e.g., Nagamachi, 1989, 1995), introduced at the start of the 1970s. This is a methodology for product development that translates the feelings, impressions, and emotions of users and customers into concrete design parameters (see Schütte et al., 2008; see also Osgood, Suci, & Tannenbaum, 1957). Central to the Kansei Engineering approach is the translation of affective values into concrete product design parameters (Barnes & Lillford, 2006). One aspect of the Kansei approach that, on the surface at least, would seem very similar to some of the research outlined/proposed here comes from the stress it places on the importance of the impression a person gets from each of their senses. However, the Kansei approach differs from the cognitive neuroscience approach in that it doesn't say much about how the senses interact (i.e., the topic of multisensory integration that has been such a central part of the material covered in this volume). What is more, the Kansei approach tends to emphasize the subjective evaluation of products by people: That is, extensive use is made of semantic differential scales (Osgood et al., 1957), involving people self-reporting against pairs of bipolar adjectives (such as attractive–unattractive, traditional–not-traditional) on Likert-like scales. By contrast, the cognitive neuroscience approach outlined here tends to be very wary (not to say downright skeptical) of subjective report, given the many occasions on which it has been shown to lead to misleading outcomes.

It is though important to note the important multisensory challenge that is lurking here, especially in the context of supermarket shopping. For, according to Sacharow (1970), the average shopper spends (or at least they did in the 1970s) just under half an hour shopping on a typical trip to the supermarket. In that time, the shopper will select approximately 14 items from a range of 6300 on display (according to Robinson, 1998, p. 172, the range of available items has jumped to 17,000–20,000, though the duration of the typical shopping trip hasn't changed). Clearly, by itself, pleasant touch isn't going to be enough to guarantee capturing the attention of the consumer, especially when as many as 60–75% of purchases are made on impulse (see Miodownik, 2005; Robinson, 1998, p. 204; Sacharow, 1970; Schoormans & Robben, 1997; see also Dickson & Sawyer, 1990), although that said, supermarkets set up displays at the end of aisle with just this end in mind (see Robinson, 1998, pp. 179–180). What one also needs are visually attention-capturing product/packaging attributes as well (e.g., see Barnes & Lillford, 2006; Garber et al., 2008; Schindler, Berbaum, & Weinzierl, 1987; Spence & Piqueras-Fiszman, 2012). In the context

of the present chapter, such attention-capturing visuals clearly need to be carefully coordinated with the tactile product attributes in order to ensure a final impression that is as multisensorially congruent (or, on occasion, incongruent) as possible.

One of the most important challenges currently facing marketers and product designers concerns how to use tactile design in order to reach out to the rapidly growing aging population. Given the current paucity of research in this area it will be critical to develop our understanding of how this heterogeneous group (see “The Silver Dollar,” 2008) respond to the tactile aspects of product design/marketing interventions. For example, one might expect that age differences will determine/interact with changes in older people’s need for touch. Indeed, as previously mentioned, it is now well known that aging leads to reduced tactile sensitivity (e.g., Deshpande, Metter, Ling, Conwit, & Ferrucci, 2008; Lin et al., 2005; Nusbaum, 1999). This means that products need to be designed in order to meet the specific needs, and desires, of the different sections of the population. In fact, one thing that elderly people often complain about (perhaps more than other sections of the population) is that no one wants to touch them (see Field, 2001). Thus products that promise to fill this need for tactile stimulation are likely to represent a successful marketing proposition.

It is interesting to note that, at the present time, most of the marketing seems to be directed at the younger/middle age rather than to the older section of the population (Underhill, 1999), although the trend seems about to change (see Kohlbacher & Herstatt, 2008). Here it may be particularly worthwhile to investigate whether there are any changes in the need for touch (as assessed, for example, by the Peck and Childers’ (2003a, b) “Need for Touch” questionnaire, see Table 11.1) for people at different stages of the lifespan. We would predict that older people should score higher on their need for touch (see Field, 2001). Should such a result be obtained, this would provide information as to how and when this change occurs (i.e., at which age), and just how physiological decline relates to psychological needs. However, one simple to implement suggestion is that packages should be made smaller for older adults, since they are likely to be part of a smaller household (“The Silver Dollar,” 2008).

A further important issue for future research relates to the development of online sales. Intuitively, it has been suggested that goods requiring multisensory input in order to be evaluated and selected by the potential customers will be less likely to be purchased over the Internet (see section 11.7.3). Yet, on the other hand, the more senses a brand engages with, the closer the bond with the customer is likely to be (Lindstrom, 2005; Neff, 2000; Vickers & Spence, 2007). Not surprisingly, then, the products that consumers are most willing to purchase via electronic means are those they are most familiar with. Products such as music CDs, videos of favorite movies, previously purchased apparel items, and basic computer equipment lend themselves to Internet-based purchases. Those shopping situations in which the consumer feels the need to acquire product information through tactile experience, where the consumer is uncertain as to the specific product being sought, or where the consumer pursues non-product-related shopping benefits (e.g., social benefits) will be slower to successfully adapt to an electronic (or home television sales) format.

How then can Internet-sales companies deal with the lack of tactile input that their customers experience when buying online? The challenge here is related on the one hand to the development of technologies capable of delivering credible and reliable tactile sensations over distance, and on the other to the use marketing strategies that somehow allow people to “touch before buying.” Until such time as haptic VR for the home market has improved dramatically (and the cost has dropped substantially), we may see customers increasingly going to the store in order to experience the tactile attributes of the products that they are considering buying, only then,

once they have made their product selections, returning home empty-handed in order to make their purchases over the Internet and so save money, rather than moving to the check-out (see Underhill, 1999).

A final important topic requiring research attention relates to the question of what is (and what is not) pleasurable to touch (see Gallace & Spence, 2011, for a review of the cognitive and neural basis of tactile aesthetics). That is, if a given product is designed to appeal to the customer's sense of touch, it is critical to know under what specific forms of stimulation people report pleasant tactile experiences. This will require a better understanding of touch blends, such as the feel of "naturalness," or whatever tactile attribute/sensation happens to come into fashion next. A thorough investigation of the more hedonic aspects of touch would seem a necessary step in order to help companies to design new and more pleasurable products for their market.

11.7.3 Tactile marketing in the era of virtual shopping

Another important challenge for companies at the present time relates to the rapid expansion of home and virtual shopping (see also Chapter 9). Over the last few years, people have started to make an increasing proportion of their purchases via the Internet and/or via home-shopping channels on the TV (see Robinson, 1998; cf. Waterlander, Scarpa, Lentz, & Steenhuis, 2011); That is, under conditions where they are isolated from the full multisensory product experience (see Spence, 2008, 2012d; Underhill, 1999). Companies are therefore increasingly finding themselves in the situation where their potential customers are no longer able to touch, feel, smell, or even hear their products when weighing up whether or not to purchase them. As a consequence, potential customers are increasingly making their purchase decisions on the basis of nothing more than the visual attributes of the product and/or on the basis of other (less reliable; cf. Szybillo & Jacoby, 1974) product-extrinsic features such as price, brand, and the reliability of the website concerned. Note that this may well lead to potential problems when it comes to buying products such as clothing where fit and comfort are key. In this case, the lack of a "try before you buy" possibility often leads to unsatisfied customers. That is, the absence of tactile stimulation in online sales might help to explain the relatively slow growth of Internet firms catering to retail consumers (see Zuckerman, 2000).

One of the most important reasons why consumers don't use the Internet in order to make their product purchases relates to the lack of multisensory experiences associated with the medium (see Phillips, Donoho, Keep, Mayberry, McCann, Shapiro, & Smith, 1997). Figuring out how to get "in touch" with the "web-savvy" consumer therefore constitutes one of the most significant challenges for many companies in the marketplace today (and for the foreseeable future). Two possible directions that researchers could take in order to address these important problems are: (1) To study the effectiveness of sending product samples "on-demand" to online customers before the actual purchase; (2) Investigating the possibilities associated with the use of VR technologies to deliver stimulation that can more effectively mimic those elicited by the actual contact with the product (see, for example, the "foot glove" project, for the possibility of using augmented reality facility to try, fit and even customize products without actually trying them; e.g., Mottura et al., 2007; see also Chapter 9).

The intrinsic qualities of a product, such as its color, smell, or tactility can sometimes be more important in determining its perceived quality than the product-extrinsic cues, such as brand name, price, and store image (e.g., Szybillo & Jacoby, 1974; Underhill, 1999). One oft-touted solution to provide this blend of sensory information comes from the suggestion that haptic

VR devices might soon be used to deliver realistic tactile/haptic (and multisensory) experiences to the potential consumer while sitting in their own home (e.g., Magnenat-Thalmann, Volino, Bonanni, Summers, Bergamasco, Salsedo, & Wolter, 2007). In Chapter 9, we saw how far virtual haptic devices have come over the last 20 years (see also Alper, 1999). Despite this recent progress, however, we are still a long way from commercially viable (and realistic) haptic interfaces that can bring the tactile attributes of the retail shopping experience into the average home. That is, claims regarding the use of VR for home shopping within the next few years, would appear rather far-fetched at the present time. This is not to say that there are not very promising devices that allow a person to haptically explore 3D virtual objects (see, for example, the Phantom by SensAble Technologies, Inc. or the Falcon by Novint Technologies, Inc.), but that, at the moment, such devices are rarely found in our homes. Moreover, it is unclear whether these devices will ever be able to deliver the subtle differences in product/texture that increasingly distinguish many of the different products/brands in the marketplace. Given these limitations, it seems unlikely that companies will be able to provide the shopper with an appropriately realistic, and nuanced haptic tactile experience by means of the home computer anytime soon (though see the progress that has been made to the simulation of *textiles* by means of force feedback devices; e.g., Magnenat-Thalmann et al., 2007; Volino et al., 2007). For the moment though, it would therefore seem that for those brands that have tactile brand capital, in-store shopping remains the only solution. Alternatively, given the recognition of the importance of, but the inability to provide, tactile product experience over the Internet, the alternative solution for companies would appear to be for them to simply facilitate the return of unwanted products (cf. Citrin et al., 2003; Quick, 1999).

11.8 Conclusions

The review of the literature on tactile marketing presented in this chapter has highlighted just how important touch is to a customer's evaluation of many products (e.g., Fiore, 1993; Fiore & Kimle, 1997; Holbrook, 1983; cf. Heslin & Alper, 1983). Even more important is the observation that people, and consumers in particular, seem to report a "need for touch" regarding certain classes of product that they might be considering buying (e.g., Citrin et al., 2003; Heslin & Alper, 1983; McCabe & Nowlis, 2003; Peck & Childers, 2003a, b, 2006). The research reviewed here has shown that touch can have a profound effect both on consumer's product evaluation responses and also on sales. Although an unequivocal answer as to why touch has such a profound effect is still lacking (primarily due to the scarcity of empirical research in this field), there are a number of different possibilities that need to be considered: First, touch has been shown to have a highly emotional value (i.e., in terms of its ability to generate pleasant experiences as well as to communicate emotions; see Gallace & Spence, 2010a; Haans & IJsselstein, 2006; Sonneveld & Schifferstein, 2008; see also Chapter 7). Indeed, it has been demonstrated that our skin contains receptors and neural fibers that are directly involved in eliciting emotional responses (Löken et al., 2009; Winklermann, 1959; see also Francis et al., 1999; Chapter 2). Although evidence regarding the emotional valence of tactile stimulation has primarily been provided by studies of human-to-human interactions (i.e., interpersonal touch), common sense suggests that this could also be true for human-to-object interactions (see, for example, the emotional valence of the transitional objects to infants, as described by Winnicot, 1964; see also Peck & Wiggins, 2006; Sonneveld & Schifferstein, 2008, for a discussion of this point). As a consequence, information regarding a given product (e.g., the name or brand) that has been explored haptically can be linked neurally with the pleasant emotions elicited by the touch of the product itself. That said, it should be noted that there may also be important differences between the patterns of brain activation seen

following intrapersonal (i.e., touching the self), interpersonal (being touched by another), and our touching of an inanimate object (see also Sonneveld & Schifferstein, 2008).

As far as the role of emotional content is concerned, the suggestion that has been outlined here is that “*affective ventriloquism*” might influence a person’s judgment concerning the qualities and pleasantness of a given product. That is, under those conditions where touch is important for product choice, the emotional sensations elicited by this sensory modality might be the more effective in modulating people overall (multisensory) product experience (and might modulate the sensations perceived by other sensory modalities). The mathematical modeling of such affective multisensory interactions using the MLE procedure was outlined as a potentially fruitful area for future research. An alternative interpretation of the effect of touch in product evaluation concerns the fact that touch seems to provide a direct and more intimate connection with the product. Indeed, in order to touch a given product, a consumer needs to reach out and actively explore it. Therefore, the perception of acting upon an object, deciding when, where, and how to explore it by establishing a direct connection with it (and not merely being a passive spectator), might provide an important dimension to the hedonic experience of those products that can be explored haptically (Gallace & Spence, 2008b; see also Chapter 12). We have also mentioned in Chapter 1 that touch has often been considered as the sensory modality that cannot be fooled (i.e., as being, in some sense, the most reliable of the human senses; see Rock & Victor, 1964; Spence, 2011b; Spence & Gallace, 2008), therefore people might feel more confident about buying something that they have touched before rather than something that they have only seen (cf. Grohmann et al., 2007). It may well be that touch provides the most reliable estimate regarding a product’s hedonic value. As such, touch might appeal to more basic needs and perhaps automatically generate liking/disliking responses at both an explicit and implicit level (Grohmann et al., 2007; Williams & Bargh, 2008). Unfortunately, however, as far as this point is concerned, research has only dealt with the more social aspects of touch (where it has been shown that tactile sensations affect physiological parameters; e.g., Edens, Larkin, & Abel, 1992). Whether or not the interaction with more or less pleasant products (rather than social interactions) leads to changes in people’s physiological state (e.g., their heart rate, skin conductance, etc.) is a research question that cognitive neuroscientists will need to address in the coming years. In Chapter 12, we will discuss the aspects related to an aesthetic of touch and their use in a number of cultural contexts.

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Chapter 12

Touch in the museum: Sculpture, art, aesthetics, and visual impairment

Taste is not content with seeing, with knowing the beauty of a work; it has to feel it, to be touched by it.

(François-Marie Arouet (Voltaire), “Goût,” in *Diderot and d’Alembert*, *Encyclopédie*, p. 761, cited in El-Khoury, 2004)

12.1 Introduction

In 1953, when Jim Watson was asked by one of the audience at a conference talk he was delivering in Cambridge for a justification of the double helix that Crick and he had discovered to constitute the structural shape of DNA, he couldn’t help but answer: “It’s beautiful, so beautiful!” (Crick, 1988; see also Galzigna, 1993). Aesthetics judgments are a constant and unavoidable part of our life, spreading across both the arts and the sciences. Indeed, it is not uncommon for scientists to choose among competing theories on the basis of aesthetic criteria (e.g., McAllister, 1998). Surprisingly, however, it is only in more recent years that researchers have really started to address the cognitive and neural correlates underlying the perception of beauty in the visual arts (e.g., see Kawabata & Zeki, 2004). In this chapter, we will address this topic from the point of view of the sense of touch.

Today, when talking about aesthetics, it seems obvious to think about visual experiences: A breathtaking picture, a sublime landscape, a beautiful man/woman, all provide classic examples (see Coleman, 1965). It is rather surprising, therefore, to observe that despite this association between “vision and beauty,” so many of our most pleasurable experiences actually result from the stimulation of the sense of touch. Without the need to talk about our romantic, sexual, or intimate experiences (where touch, of course, assumes an especial importance; e.g., Frohlich & Meston, 2005a; Kahneman, Krueger, Schkade, Schwarz, & Stone, 2004; Morris, 1971; see Chapters 7 and 13), there are a number of everyday situations in which the sense of touch makes an important contribution to our overall perception of events. One may think, for example, of the sensation of the body being pressed against the seat when accelerating in a sports car, or the feeling of warm water flowing against the skin when swimming in the Mediterranean, or the friction of the snow against the skis when skiing, and so on. These examples, taken from the world of sport, could be extended endlessly into other domains of our life (think, for example, of the feeling of melting chocolate in your mouth; see Chapter 14). It is clear, therefore, that many of our everyday experiences will not be anything like as beautiful or enjoyable if tactile experiences were not there to be appreciated! But are tactile sensations beautiful in their own right? And, more importantly, to what extent does tactile information contribute to our global (or multisensory) aesthetic experiences? It should be noted at this point that very few of our perceptions (especially the most

pleasurable ones) occur in isolation; instead, the senses of vision, audition, olfaction, taste, and touch are often stimulated concurrently (even if we are not always aware of these stimuli in their entirety)!

Despite the importance of touch as a communicative and emotional sense (e.g., Gallace & Spence, 2010a), very little research has addressed the more hedonic aspects of tactile information processing (though see Francis, Rolls, Bowtell, McGlone, O'Doherty, Browning, Clare, & Smith, 1999; Sonneveld, 2007, for exceptions; see also Diaconu, 2003, 2006; Lindauer, 1986; Lindauer, Stergiou, & Penn, 1986; Silverthorne, Noreen, Hunt, & Rota, 1972). What, then, is considered pleasurable to touch? How can particular tactile sensations be considered “beautiful?” Do we need a new language for tactile aesthetics? What are the neurological substrates associated with the appreciation of tactile stimuli? These are just some of the important questions awaiting a clear answer from the scientific/artistic community.

This lack of research on the aesthetic aspects of touch is rather surprising if one considers that many artists in different periods of human history have used the power of touch for their communicative purposes (even if often only represented by means of a visual medium). For example, in one of the most famous examples, Michelangelo used the sight of imminent touch in the Sistine Chapel in Rome to evoke what, from a religious point of view, is one of the most important moments for humankind, the very beginning of human history: the creation of the first man. God approaches the hand of Adam to deliver the “gift of life” and is portrayed almost touching it (see Figure 12.1). Surprisingly, the highly communicative power of touch (by the reproduction of contact between the fingers) was used by the Italian artist despite the necessity of reporting accurately the biblical message. Indeed, in the Bible, God is described in the act of blowing into Adam's nostrils in order to give him life, rather than touching him with His fingers as Michelangelo chose to depict it. Perhaps, the original biblical gesture was replaced by the finger-to-finger touch in order for the artist to communicate a more “humane” nature of God (see O'Rourke Boyle, 1998, on this point).

In this chapter, we will make a preliminary investigation into what characteristics an “aesthetics of touch” ought to possess. First, we analyze the point of view of those artists who have used touch in their work and then the suggestions that have emerged from the study of visual aesthetics. Next, we discuss the need to create tactile replicas of artifacts to be used in museums and art galleries by visually impaired as well as sighted individuals. Finally, we explore the possible neural correlates



Fig. 12.1 A section of Michelangelo's fresco Sistine Chapel ceiling painted c.1512 representing the creation of Adam. Hands of God and Adam, detail from *The Creation of Adam*, from the Sistine Ceiling, 1511 (fresco) (pre restoration), Buonarroti, Michelangelo (1475–1564)/Vatican Museums and Galleries, Vatican City/The Bridgeman Art Library.

of the more hedonic aspects of tactile perception with the aim of providing testable hypotheses regarding the possible neurological basis of the aesthetics of touch.

From this analysis, we demonstrate that tactile aesthetics has both a number of similarities and also a number of important differences from visual aesthetics. In particular, we put forward the suggestion that tactile aesthetic experiences might be more “primitive” (from an ontogenetic¹ point of view) than visual aesthetic experiences. That is, we speculate that visual aesthetics might derive, at least to a certain extent, from tactile aesthetics. The peculiarities associated with the hedonic aspects of touch make this sense a powerful, but at present underutilized, channel for artistic communication.

12.2 The artist's viewpoint

Artists and designers love physical objects, especially if they have had a hand in making them. When people experience an art object tactilely, actually hold it in their hand, they understand something of what the artist was thinking when they created it.

(Munoz, 2003, p. 9; in Street & Lewis, 2001)

The sense of touch has often been used by artists in both visual and tactile forms of art (that is, pieces of art explicitly made to stimulate only or also the sense of touch) throughout the centuries. As far as purely tactile forms of art are concerned, it is important to note that ever since the Renaissance, art (and, in particular, the medium of sculpture), has been directly linked to the sense of touch (e.g., Berenson, 1894; Etlin, 1998; Merleau Ponty, 1945; though see also Hall, 1999). Similarly, the use of touch constituted a particularly important aspect of the twentieth-century art movement known as “Futurism.” Filippo Tommaso Marinetti defined “Tattilismo” (or the “Art of Touch”; seen as a “multisensorial” evolution of Futurism) as a central aspect of his newly created movement (see Marinetti, 1921a). In particular, the founder of this artistic movement wanted to enhance the sensitivity of the skin, which he described as “still a mediocre conductor of thought,” through the haptic experience of “tactile boards” (these were artworks made of different materials such as tinfoil, sponge, feathers, etc.), called “hand journeys” (e.g., Marinetti, 1921a, b; see Figure 12.2).

It is undoubtedly true that visual forms of artistic expression have a privileged position in society today. That said, in more recent times, touch seems to have regained the interest of a new generation of artists, including, amongst others, Ernesto Neto, Lilli Muller, and Rosalyn Driscoll. Let's start, therefore, by looking at what one of these artists has to say about tactile art:

It [tactile art] is intimate, drawing us into relationship with what we are touching. It is active rather than passive, requiring us to reach out and explore. It grounds the experience in perception rather than concept. Aesthetic touch deepens our knowledge of sensuous reality. We recognize an apple by looking at its colors, shape and size; by touching it, we come to know its weight, mass, temperature, texture and ripeness. If we are touching a sculpture, we feel the massing of forms, the texture and temperature of surfaces, the qualities of materials, the nature of spaces. (Rosalyn Driscoll; <http://www.rosalyn-driscoll.com/pages.php?which_page=book_introduction> downloaded on June 26, 2008; see Figure 12.3, for an example of Rosalyn Driscoll's art work)

From this brief description of tactile art by Rosalyn Driscoll, a number of important differences between our aesthetic experience of objects perceived by touch and vision emerge. In particular,

¹ “Ontogenesis” refers to the origin and the development of an organism (e.g., from the fertilized egg to the mature form), as distinct from “phylogenesis” which refers to the evolutionary history of species.



Fig. 12.2 *Sudan-Parigi* ("Sudan-Paris"), tactile board by Filippo Tommaso Marinetti. 1922, mixed materials, Geneva, private collection.



Fig. 12.3 *Homage to Turner* by Rosalyn Driscoll. Picture courtesy of the artist. Photography by David Stansbury.

the appreciation of art by touch appears to involve a certain level of "intimacy" that is not required (or at least required to a lesser extent) in the appreciation of visual art forms. Indeed, one may note that the sense of touch has always been associated with intimate relationships (see Ellis, 1936; Gibbs, Howard, Kjeldskov, Vetere, & Satchell, 2006; Lee & Guerrero, 2001; see also Gallace & Spence, 2010a). Montagu (1971) went so far as to suggest that touch and love were indivisible! Somehow, from the artist's perspective, touch seems to lead to a closer, more sensuous, and deeper knowledge of reality as compared to the visual modality (e.g., Montagu, 1971). For this very reason, tactile art appears to be more perceptual and emotional than conceptual in nature. "of all the great sensory fields, the field of touch is at once the least intellectual and the most massively emotional" was the way Ellis put this concept back in 1937 (Ellis, 1936, p. 41).

Moreover, as far as this point is concerned, one might also suggest that those sensations that tactile art evokes are more "primitive" (from an ontogenetic point of view), than those evoked by visual art forms (cf. Everett & Gilbert, 1991). For example, soft and warm tactile sensations might unconsciously remind us of our earlier experiences in the womb and therefore be perceived as

particularly pleasant (note that the sense of touch is the very first sense to develop in the womb, reaching maturity well before the others; e.g., Atkinson & Braddick, 1982; Bernhardt, 1987; Bremner et al., 2012; see also Fitzgerald & Gibson, 1984). This observation also leads on to the suggestion that both implicit and explicit memories might play an important role in our aesthetic judgments of haptically explored stimuli (e.g., Harrison, 1977; Zajonc, 1968; see Chapter 5, for a review of what is currently known about tactile memory).

Another important issue to highlight from Rosalyn Driscoll's quote is that tactile art is "active"; it needs the "viewer" (if that is the right word) to reach out, to move his/her body and explore in order to appreciate something. That is, the perception of acting upon a piece of art, deciding when, where, and how to explore it (and not merely being a passive spectator), would appear to provide an additional dimension to our hedonic tactile experiences. Note that this characteristic is also common to the appreciation of sculpture, the form of visual art that might be considered the closest to tactile art (e.g., Berenson, 1894). The important role of action in the appreciation of art also seems, at least in part, to be related to the fact that tactile perception is strictly linked to our body and to the way in which it moves in/through space (e.g., Gallace & Spence, 2008a, 2010b; see also Vaishnavi, Calhoun, & Chatterjee, 2001, for the claim that people tend to orient their attention away from the body during visual exploration while orienting toward it during tactile exploration). As we saw in Chapter 2, the tactile sense constitutes a kind of "composite" sensory modality derived from the integration of different forms of information (e.g., cutaneous, kinesthetic, and haptic; see Klatzky & Lederman, 2002). All of these aspects of tactile information processing therefore need to be considered carefully in order to fully appreciate the possible foundations of tactile aesthetics.

12.3 Tactile and visual aesthetics: Similarities

The field of tactual aesthetics lacks insight in such underlying principles. To develop the research field of tactual aesthetics, future research should focus on the underlying principles of aesthetic experience, thus possibly revealing some universal tactual Gestalt principles, and revealing insight in relations between aesthetic experience and interaction factors such as exposure frequencies (Hekkert, 2006).

(Sonneveld & Schifferstein, 2008, p. 64)

In order to discuss the possibility of an aesthetics of touch, it may be helpful here to take a step backward and to look at the general definition of "aesthetic," regardless of the sensory modality involved. The *Oxford English Dictionary*, for instance, defines aesthetic as: "concerned with beauty or the appreciation of beauty." More complex definitions can be found in the relevant literature: Baumgarten, in his seminal two-volume work *Aesthetica* (1750, 1758), made use of a distinction proposed even earlier by Leibniz between "intellectual" and "sensuous" knowledge, giving the name aesthetics only to the latter. He went on to define sensuous knowledge that gave satisfaction or pleasure as being of the "beautiful." Beauty and pleasure here seem to constitute a pair of indivisible concepts (see also Beebe-Center, 1932). Two of the questions that naturally follow would therefore seem to be: What is beautiful to touch? And, what is pleasurable to the sense of touch? As far as these questions are concerned, one might note that the very idea of describing a tactile sensation as "beautiful" might appear somehow awkward (especially to many normally sighted individuals).

In some sense, the concept of beauty seems to be a quality owned only by certain visual, auditory, and even olfactory stimuli (a beautiful picture, a beautiful tune, a beautiful landscape, a beautiful fragrance, and so on; see Coleman, 1965). The very language of aesthetics seems to be

centered on the characterization of visual and auditory stimuli (see, for example, the concepts of harmony and proportion; e.g., Arnheim, 1956). What, then, are the properties that a visual object must have in order for it to be considered as beautiful? An analysis of these properties might be helpful to our understanding of whether or not these very same qualities are also shared with the tactile modality. Note that a fully comprehensive list of topics thought to be relevant to visual aesthetics goes well beyond the scope of the present review. Therefore, we will concentrate here on only a limited number of important concepts, those where some sort of agreement seems to have been attained by researchers and art experts.

12.3.1 The Gestalt laws

There are several attributes that psychologists and art experts consider important to our experience of beauty (see Arnheim, 1956, for a review). A first set of these attributes are the Gestalt laws (e.g., Wertheimer 1912/1961, 1923/1938; see Chapter 3). Humans appear to consider objects or forms that respect the Gestalt laws as being more beautiful than those structures that do not possess these properties (see Arnheim, 1956). One may, for example, observe that we all have a predilection for the “Golden ratio” (1:1.62; see Fechner, 1865) in art and architecture (used, for example, in the Parthenon in Athens, the Great Pyramid of Giza, and in Leonardo’s *Mona Lisa*; though see Boselie, 1992). Many visual artists, such as Maurits Cornelis Escher, Leonardo, Paul Klee, Josef Albers, to cite but a few, have, to a certain extent (and more or less explicitly), exploited the Gestalt laws in their work (see Arnheim, 1956; Penrose, 1973, for a discussion of this point). The fact that certain general laws seem to regulate our perception and hedonic experiences, makes one speculate about whether these principles are innate and hard-wired in the human brain or whether instead they are acquired over the course of experience. Both explanations seems to have a certain degree of support from the available psychological and neuroscientific research, but a definitive conclusion to the debate appears, as always, some way off (e.g., Di Dio, Macaluso, & Rizzolatti, 2007; Quinn, Kelly, Lee, Pascalis, & Slater, 2008; Rhodes, 2006, for discussion of this point).

As extensively discussed in Chapter 3, the literature clearly suggests the presence of certain Gestalt principles in the perception of tactile objects and materials. However, the question of whether or not these very same principles also govern our aesthetic appreciation of tactile experiences still remains to be investigated.

12.3.2 The average

In his seminal work, Daucher (1979) superimposed the pictures of 20 young women, thereby obtaining an “averaged” image of a girl. He then asked a group of individuals to judge which of a series of pictures, comprising both the unmodified pictures and the averaged images resulted in the most beautiful girl. On average, the participants judged the composite picture as being more beautiful than the originals. This result led the author to conclude that our “models” of beauty are somehow learned from the sum of many different experiences.² Here, also, one may think

² It is important to note here that averaging also leads to an increase of symmetry in the final stimulus. That is, people might also find that average stimuli are more beautiful because they are more symmetrical. In fact, from an ecological point of view a more symmetrical organism might be considered more healthy or fit than an asymmetrical one. That is, subtle departures from symmetry may reflect poor development or exposure to environmental or genetic stress (see Wade, 2010, for a review on the relationship between symmetry and attractiveness; see also <<http://www.guardian.co.uk/science/2008/aug/18/sexual.selection.body.symmetry>>, downloaded on November 9, 2012).

of Pliny's anecdotal observation, circa 77 AD, that the Greek painter Zeusi created his portrait of the mythologically perfect beauty "Helen" by taking inspiration from five of the most beautiful girls of Croton (see Pliny, 1938; see also Maffei & Fiorentini, 1995). Unfortunately, no study has as yet investigated the presence of an aesthetic preference for "average" objects when explored haptically. This might be, at least in part, caused by the technical difficulties that one is likely to experience in terms of creating tactile objects that are, in any sense, "average." That is, what are the characteristics of the objects that should be "averaged"? Texture, shape, density are some of the many candidate sensory attributes. Certainly the most recent progress in 3D engineering (see, for example, the development of 3D printers) as well as the new insights coming from the study of the tactile sensory system will help researchers to tackle this question in the near future. Another possible way to study the role of average in tactile aesthetics might be to realize an average image out of a number of visual stimuli (e.g., faces) and then to make a tactile version of it (e.g., a mask). However, in this case one might wonder if the same kind of average affects both vision and touch.

12.3.3 Memory

The importance of prior experience in aesthetic judgments has been highlighted in a series of studies in which participants had to express their preference for pictures taken from a completely new, or already seen, set of images. The results demonstrated that previous exposure to stimuli can increase people's subsequent preference for those stimuli (e.g., Harrison, 1977; Zajonc, 1968; see also Temme, 1984; Zajonc, 1980, 2001). Surprisingly, this "mere exposure effect" (see Chapter 11; and see Cutting, 2006, 2007, for a discussion on the use of the mere exposure effect in art), as it has been named, was strongest when the stimuli were presented subliminally, such that subsequent recognition performance fell to chance level (e.g., Bornstein & d'Agostino, 1992; Kunst-Wilson & Zajonc, 1980). It is important to remind the reader here that, as seen in previous chapters, the presence of a mere exposure effect has also been reported for objects that have been only explored haptically (e.g., Jakesch & Carbon, 2012) and that this effect transfers from one sensory modality to another (e.g., from visual to tactile stimuli; see Suzuki & Gyoba, 2008).

12.3.4 Superstimuli

By analyzing prehistoric pieces of art, such as the Venus fertility figures, Ramachandran and Hirstein (1999) came to the conclusion that an appreciation for art is also related to the "amplification" of nature made by the artist (in addition to the abstraction resulting from many experiences of the same stimulus), resulting in the creation of a "super stimulus" (see Ramachandran & Hirstein, 1999, for a definition of the "eight laws of aesthetic experience"; though see Carey, 2005, for criticism of these authors' theory based on the difficulties of applying scientific research to art).³ Here it is important to fully understand this concept before moving forward in our analysis. In the field of ethology, a superstimulus is defined as an exaggerated version of a stimulus to which there is an existing, often genetically determined, response tendency, or any stimulus that

³ "Before dismissing Ramachandran and Hirstein as the Laurel and Hardy of neuroaesthetics, however, we should remind ourselves that they are, in fact, highly distinguished academics: Ramachandran a professor of neuroscience and psychology at the University of California; Hirstein, philosophy professor at William Paterson University. So their theory's hopeless ineptitude illustrates the difficulty of applying scientific research to art, even when fine minds attempt it" (Carey, 2005, p. 74).

elicits a response more strongly than the stimulus that normally elicits it (e.g., Baerends, 1982; Mackintosh, 1974). For example, Konrad Lorenz (1961) observed that certain birds would select for brooding, eggs that resembled those of their own species but just so happened to be larger. Translated into the language of aesthetics, these observations would therefore suggest that we like the amplification of those characteristics of the world that we have been somehow selected to like (for the fitness of the species). As Ramachandran and Hirstein suggest, this might be the case for the Venus fertility figures, where breasts and hips were disproportionately enlarged by the artist who made them (see also Maffei & Fiorentini, 1995). That is, it might be possible for reasons related to the improvement of evolutionary fitness, that we learn, or we are genetically programmed, to find certain aspects of nature or particular stimulus configurations attractive (see also Honekopp, Rudolph, Beier, Liebert, & Muller, 2007, for evidence that female judgments of the attractiveness of pictures of the male body correlate with the estimated physical fitness of the male concerned).

Interestingly, something that is not often mentioned about the Venus figures, such as the “Venus of Willendorf” (currently displayed in Vienna’s Naturhistorisches Museum) is that this work seems to be made to be touched (see Lewis & Lewis, 1994). Can it be any coincidence, one might wonder, that its size (11.1 cm), and even its shape, fits perfectly into the palm of the hand. Even more relevant to this claim is the fact that the statue’s feet do not allow it to stand on its own. That is, it seems likely that the Venus had to be held in the hand in order to be fully appreciated. The meaning of this sculpture, and of other similar statues from the Palaeolithic period, is still much debated by anthropologists. Possible interpretations include: the representation of security and success, a fertility icon, a pornographic image, a direct representation of women/a Goddess, or even a self-portrait (e.g., McDermott, 1996). That said, the sculpture’s intimate relationship with the sense of touch certainly appears important. The discovery of these kinds of artistic works might be taken to suggest that certain aspects of our visual preferences might be derived from certain innate tactile preferences. Of course, this speculative suggestion would need to be verified empirically before assuming the status of any kind of scientific fact.

In Chapter 7, we talked about Harlow’s (1958) experiments on baby monkeys, showing that these animals prefer soft surrogates of their mothers over surrogates made from shaped metal wire. On the basis of such results, it is certainly plausible to think that a predilection for soft sensations (i.e., a furry teddy bear might be considered a sort of superstimulus here) is also present in human babies (cf. Anisfeld, Casper, Nozyce, & Cunningham, 1990), although (as far as we are aware) no study has ever been conducted in order to verify this claim empirically (note, however, that soft objects such as teddy bears and blankets are the first toward which the baby establishes relationships that go beyond the comforting one provided by his or her mother; see Chapter 7, for a discussion on this point). By contrast, studies in adults clearly highlight a preference for soft sensations in a number of different contexts (e.g., Kergoat, Giboreau, Nicod, Faye, Diaz, Beetschen, & Meyer, 2012).

Christian Carbon (2010) published one of the first studies to analyze people’s visual preferences for cars designed in different periods in the history of car making. Interestingly, he found that people tend to prefer cars with more curved shapes. This result, together with the observation that curved haptic sensations are the very first to be experienced by humans (e.g., in the womb) might be taken to suggest that certain haptic qualities related to the shape of objects are naturally preferred over others, just as for their surface qualities (i.e., their softness).

As far as this point is concerned, further research should investigate the more general question of what kinds of stimuli people like to touch (as well as what kinds of stimuli they do not like to

touch; e.g., Kitada, 2012) and, eventually, if any preference that is found should be considered as being innate or else reflect the result of learning (i.e., by studying the tactile preferences of newborn babies). In babies this might be tested by providing them with a number of different textures and shapes and observing their behavioral reactions (i.e., facial expression, changes in sucking behavior, duration of exploration, etc.) to each and every one of them. The presence of innate tactile preferences in adults should also be tested in participants from different cultures and using stimuli, varying in terms of their shape, texture, size, weight, and perhaps even temperature (see Picard et al., 2003, for the rating of tactile textures in adults). A number of studies where such testing procedures have been adopted actually confirmed that people tend to prefer softer materials (e.g., Major, 1895; Ripin & Lazarsfeld, 1937). Note, though, that no study has ever tested participants belonging to different cultures in this regard. The role of more cognitive factors on participants' hedonic judgments would likely also be worth investigating. For example, one might expect that the same object will be perceived as more or less pleasant as a function of people's knowledge regarding the characteristics of the person who owned it.⁴ Similarly, different tactile aesthetic judgments might be expected if the object has previously been described as a very rare/ancient, or rather as a modern and mass-produced item. The results of these studies will not only be of theoretical relevance but they will also have important practical implications (i.e., for the developments and marketing of products that automatically and naturally elicit pleasant sensations; see Chapter 11).

At this point, then, we can summarize some of the key characteristics of the appreciation of beauty that have emerged from this brief overview of the extant literature on visual aesthetics: the Gestalt laws, the abstraction of a set of experiences, the amplification of reality, and the evolutionary importance of certain stimuli. Certainly, one also needs to add to these important factors, the emotional and more cognitive characteristics of the aesthetic experience (e.g., the appreciation of the inner meaning of an artistic work; e.g., Argenton, 1996). All of these aspects would appear to be common among visual and tactile aesthetic judgments.

12.4 Tactile aesthetics: Beyond vision

As mentioned several times already, touch is the first sense to develop. Just before the 8th week of gestation (i.e., well before the development of other senses), embryos become sensitive to tactile stimulation (e.g., Atkinson & Braddick, 1982; Bernhardt, 1987). The latest research has demonstrated that starting from the 14th week of gestation, twin fetuses actually execute movements that appear to be specifically aimed at establishing tactile contact with their co-twin (Castiello, Becchio, Zoia, Nelini, Sartori, et al., 2010). Considering this evidence, together with the fact that we like what we have previously been exposed to (e.g., Harrison, 1977; Suzuki & Gyoba, 2008;

⁴ An interesting anecdote related to the importance of cognitive factors on the appreciations of tactile stimuli comes from Professor Bruce Hood based in the University of Bristol (Hood, 2009; see also Nemeroff & Rozin, 1994). During his talks, he sometimes hands a sweater to the audience. He then asks them how much they like the feel of the material; under such conditions, people typically report that it feels fairly nice. Hood then tells his audience that the jumper actually once belonged to Fred West, the infamous serial killer, or to some other motley character. On many occasions, educated audiences will immediately discarded the object, with some individuals even refusing to touch it. This example highlights the importance of top-down factors (e.g., cognition, beliefs, memory, etc.) in the tactile appreciation of objects (see also McCabe et al., 2008). One can think of this as the opposite of people's need to touch certain relics; a piece of Padre Pio's gloves, for example.

Zajonc, 1968; see also Zajonc, 1980), one really might wonder if visual aesthetic preferences can be modeled around our early tactile experiences. That is, the empirical evidence showing that tactile contact develops, and is actively sought for, from a very early stage of development, could be taken to provide some support for the suggestion that visual aesthetics is founded, at least in part, on tactile aesthetics. Moreover, these findings also bear comparison with the suggestion by artists that the sensations that tactile objects evoke are somehow more “primitive” than those evoked by visual stimuli. Artists who have explicitly used touch for aesthetic purposes seem to suggest that the tactile sense provides a more intimate experience of beauty, as compared to the visual sense (see section 12.2). This greater intimacy would seem to be related to the role of the active exploration of the stimuli perceived via the sense of touch. One might then wonder whether empirical research can offer some support for the idea that active movement plays a major role in our tactile aesthetic preferences. Unfortunately, no study has attempted to investigate this topic previously. That said, many studies have addressed the reciprocal role of bodily movement on tactile perception. These studies have demonstrated that there is a very strong link between touch and movement, also confirmed by the observation of a close somatotopic correspondence between the neural maps that represent tactile sensations experienced over our body and those brain areas responsible for controlling its movement (i.e., those areas responsible for the perception of touch on the hands in the somatosensory homunculus are located mostly in front of the areas responsible for hand movements in the motor homunculus; e.g., Penfield & Rasmussen, 1950; see also Chapter 2).

A number of studies have also demonstrated that self-generated movement increases the detection threshold for tactile stimuli presented on a moving body part (thus making it more difficult to perceive them; see Juravle, Deubel, Tan, & Spence, 2010) and, to a lesser extent, on more remote body sites (e.g., Gallace, Zeeden, Röder, & Spence, 2010; Williams, Shenasa, & Chapman, 1998; see also Juravle, McGlone, & Spence, submitted). Interestingly, the relationship between touch and movement goes both ways. That is, movement of the body somehow impairs tactile perception, but the processing of tactile information, at least under certain conditions of stimulus presentation, cannot occur without active movement. In particular, we saw in Chapter 9 that research on the “tactile vision substitution systems” (TVSS) for the blind has shown that participants can correctly and “intuitively” perceive images taken by a video camera and translated into patterns of tactile stimulation presented on their back only when they were free to move the camera in space with their arms (e.g., Bach-y-Rita, 2004). That is, without the possibility of “actively exploring” the stimuli, the patterns of stimulation could not be correctly identified. This evidence clearly supports the view that there is a strong link between tactile perception and movement. However, whether or not this link also affects the more hedonic aspects of our tactile experiences still needs to be investigated.

Taken together, the observations and the results of empirical research mentioned in this chapter would appear to suggest that tactile aesthetics seems to have both similarities as well as a number of important differences when considered in relation to visual aesthetics. It would appear that the presence of the very same principles of Gestalt grouping within each sensory modality, and the fact that certain stimuli might somehow automatically elicit appreciative responses, constitute common aspects to both domains of study (see also Lindauer, 1986; Lindauer, Stergiou, & Penn, 1986, for evidence showing similarities among the aesthetic judgments of visual and tactile stimuli). However, certain peculiar aspects of touch, and, in particular: (1) its strong link to bodily movement and emotions, and (2) its more “primitive” nature, seems to characterize tactile aesthetics as being distinct and independent from visual aesthetics. From the brief analysis of the literature reviewed so far in this chapter, it becomes clear that very little research has been



Fig. 12.4 The installation
Gloejobabel Nudeliome
Landmoonaiia by Ernesto Neto.

addressed to investigate the processing of aesthetic material by the sense of touch (as compared to the visual modality). In particular, if one considers the concepts of “abstraction” and “amplification,” concepts that are thought to play a major role in visual aesthetics, the evidence available is even scarcer, given that no one has ever even addressed their importance in terms of making our experience of touch pleasurable.

It is worth noting here that although researchers have very little investigated the role of abstraction and amplification of nature in tactile preferences, certain artists might in some sense be said to have exploited the concept of tactile “superstimuli” in their artistic creations; see, for example, the installation “Gloejobabel Nudeliome Landmoonaiia” by Ernesto Neto (see Figure 12.4) where people can lie on top of a gigantic soft surface. This lacuna in our scientific knowledge regarding the sense of touch is all the more surprising when one considers the fact that we all, up to a certain extent, choose new clothes or new couches (and perhaps even our partners; see Sheldon & Arens, 1932; though see also Herz & Cahill, 1997) on the basis of the feel of their surface (e.g., Moody et al., 2001; Workman & Caldwell, 2007; see also Picard et al., 2003; Spence & Piqueras-Fiszman, in press).

12.5 Touch in the museum

The last few years have seen an explosive rise in the number of conferences and workshops dedicated to trying to understand how to make our museums and art galleries more accessible to those suffering from some sort of sensory impairment. Typically, these meetings bring together individuals from many different backgrounds, including museum curators, educators, psychologists, neuroscientists, those with some form of sensory impairment (as well as those working on their behalf), not to mention artists and art historians. However, while everyone involved seems to agree that something urgently needs to be done in order to make museums and galleries more accessible (or “touch-friendly”; though see Candlin, 2004), little progress has, as yet, actually been made in terms of providing concrete recommendations and/or insights with regard to how to improve the educational and/or aesthetic experience of those visiting museums and art galleries (Candlin, 2003, 2010).

One of the central questions in this area of research is: “What are the specific attributes of a museum object, artifact, or sculpture should one try to capture when creating a tactile replica (or model)?” We believe that it is only by gaining a fuller understanding of the multisensory nature of our everyday perception (and aesthetic appreciation; see also Classen, 2005; Cranston, 2003; Diaconu, 2006) of objects, and also of the dominance of certain tactile object attributes over others (i.e., shape, size, texture, etc.), that we will be able to make a more informed decision about what it is, exactly, that a tactile replica should be attempting to capture (or reproduce). These, then, are some of the most important insights that the scientific study of touch/haptics will need to provide in the years to come if we are to create educationally and/or aesthetically meaningful tactile replicas, designed to be handled by museum or gallery visitors, no matter whether or not they happen to be visually impaired.

In most museums and art galleries the pieces of art cannot be touched. However, one might wonder how people can really appreciate something designed to be touched by vision alone. It is interesting to note at this point that discrepancies between what an object feels like and what it looks like have also been reported in the context of archaeological studies of material culture. See, for example, MacGregor’s (1999) sensory analysis of a selection of Scottish carved stone balls housed at the Kelvingrove museum in Glasgow (see section 12.5.1). The English traveler Celia Fiennes noted something similar when, on her visit to the Ashmolean Museum in Oxford in 1694, she picked up a cane “which looks like a solid heavy thing but if you take it in your hands [is] as light as a feather” (Fiennes, 1949, p. 33, cited in Classen, 2005). A recent inspection of a number of contemporary design catalogues revealed the existence of a surprisingly large number of items that were specifically designed in order to feel different from what one would have been led to expect simply by looking at them (and therefore generating a sense of surprise; see Schifferstein & Spence, 2008). Similarly, the artist Miho Suganami (2003) also uses the incongruence between the senses of vision and touch in her art: For example, in the piece *Rosetta Stone III* (1997–1998) she embedded a number of hidden light bulbs inside a hollowed piece of Hollington stone in order to make a material object (stone), that one would normally expect to feel cold, actually feel warm to the touch (see also her piece *Life*, 2002; see <<http://www.suganami.freemove.co.uk/>> downloaded on October 5, 2011 for an overview of Suganami’s work). Following on from these observations it looks like leaving people touching art is the only viable option for its full appreciation.

12.5.1 How to make the best tactile replica

One way in which museum curators can make their exhibits more accessible to the blind, partially sighted, or also sighted individuals is through the provision of tactile replicas that enable people to experience haptically something of the objects and artifacts that are on display. However, it is, at present, unclear exactly what aspects of an artifact or sculpture should be captured by a tactile replica. Is it the size that is important? Or the weight, the temperature (cf. Candlin, 2004, p. 75; MacGregor, 1999, p. 265; Suganami, 2003), the texture, or the compliance of the material? We simply do not know! However, the results of Candlin’s (2003) interview study of visually impaired museum visitors clearly highlight the inappropriateness of at least certain of the current approaches. As Candlin notes after discovering that the education curator responsible for access at one large gallery provided nothing more than a chunk of limestone for visitors to touch (given the prohibition on touching any of the gallery’s collection of sculptures): “Limestone in a three inch square does not convey the scale, weight, temperature, form, texture or rhythm of the work. These qualities are not irrelevant to the art object or to an understanding of what that art work is about” (Candlin, 2003, p. 103).

This point, about what is missed when people are only allowed to handle a piece of the material from which an object has been constructed, is really brought home if one contrasts it with the richness of the tactile/haptic experiences that a person may experience if they are actually allowed to touch museum artifacts. Take, for example, MacGregor's (1999) haptic sensory analysis of a set of Scottish carved stone balls (CSBs) that he was allowed to touch:

The first thing that you notice when your hands close around a CSB is their coolness to the touch. As the lateral motion of the fingers explores the form of the object, the texture rapidly becomes apparent . . . The initial enclosure of the hands rapidly established the sub-spherical shape of these objects and the exact form of them was rapidly determined by following their contours. In the case of the balls with a limited number of knobs, the number is readily and quickly established. When a larger number of knobs are present it becomes harder to establish the exact number by touch alone. (MacGregor, 1999, p. 265).

Now there are clearly a number of problems with letting the general public touch artifacts (e.g., associated with the deterioration of the objects that would be expected following heavy petting; e.g., Candlin, 2004, 2006a, b). Nevertheless, the latter quote still serves to highlight the richness of the temporal sequence of different sensations that one may experience when actually exploring an artifact haptically, and this, presumably, is what we should be aiming for when trying to create a tactile replica.

12.5.2 Tactile replicas: The analogy with visual reproduction

It is perhaps enlightening here to consider the analogous situation involving the reproduction of visual images. Would Gericault's *The Raft of the Medusa*, for example, have the same impact on a viewer if they were to look at a reproduction of the painting in a book that might perhaps by only 1/20th of its actual size (i.e., 491 × 717 cm)? The answer is presumably "no, it would not." This observation leads to the suggestion that part of our aesthetic experience, at least of paintings, depends on their relative size (see Silvera, Josephs, & Giesler, 2002, on this point). It will be important in the future to determine whether our perception of a tactile replica of a large sculpture, for example, would be deleteriously affected to the same extent by the presentation of a small replica designed to fit snugly into the palm of the hand.⁵

Another tricky problem associated with the creation of tactile replicas in the cultural heritage context is to determine how important it is for a tactile replica to reproduce the various different materials involved in the construction of the original artifact (note also that different materials may be used in sculpture to communicate different feelings or emotions; e.g., Hall, 1999; Marinetti, 1921a, b). One need only think here of how much of our appreciation of a painting (comprehending its meaning and emotional value), such as Vassilij Kandiskij's *Red-Yellow-Blue* or Karl Schmidt-Rottluff's *The Black House* is lost when it is reproduced in black and white (see Maffei & Fiorentini, 1995). One might wonder whether the tactile/haptic equivalent here might be to reproduce an object made of many different materials, with a replica that were to be made entirely from a single material.

Finally, it is important to note that the sound, smell (and in former times, perhaps even the taste) of an artifact might be perceived as an integral part of the experience of (or at the very least

⁵ Note that some artists somehow play with the concept of making objects that in our everyday life are touchable, touchable no more by making enormous replicas of them (see, for example, *The Giant Chair* by artist Henry Bruce). That is, size certainly matters to our appreciations of tactile art as well.

influence a person's response to) an object by a museum visitor (see Arnold, 2003; Classen, 2005, 2007; Hooke, 1705/1971, for historical perspectives). This problem becomes all the more significant when one remembers that many of the objects displayed behind the glass in museums and other cultural heritage contexts were originally made in order to be touched, held, and or actively used by people (e.g., see Classen & Howes, 2006; see also Ouzman, 2001)! To what extent then should our tactile replicas be designed to mimic these non-tactile sensations associated with the object?⁶ By understanding the mechanism underlying tactile aesthetics, cognitive neurosciences in the years to come might help to provide some relevant insights for those hoping to answer these important questions.

12.6 The neuroscience of aesthetics: What about touch?

Many researchers have recently begun to address questions related to the neuroscientific underpinnings of aesthetics, even leading to the recent creation a specific field of study named "neuroesthetics" (see Zeki, 2002a, b; Zeki & Kawabata, 2004; see also the website <<http://neuroesthetics.org>>, downloaded on November 15, 2010). Not surprisingly, the vast majority of the studies published to date in this field have investigated the neural correlates of "visual" aesthetic experiences (e.g., Di Dio, et al., 2007; Jacobsen, Schubotz, Hofel, & Cramon, 2006; McKeefry & Zeki, 1997; Petra, Florian, Lederb, & Bauer, 2007; Zeki & Kawabata, 2004).

Far fewer studies have addressed the neural correlates associated with the aesthetic appreciation of "auditory" (i.e., music; e.g., Blood, Zatorre, Bermudez, & Evans, 1999), olfactory (e.g., Royet, Plailly, Delon-Martin, Kareken, & Segebarth, 2003; see Coleman, 1965, for a discussion on whether smell or touch can actually be considered beautiful) and even "gustatory" (or flavor) forms of stimulation (Small, Zatorre, Dagher, Evans, & Jones-Gotman, 2001). Note, however, that the neural mechanisms of aesthetic preference do not necessarily need to be completely different for each sensory modality (just as certain higher-order cognitive functions in different sensory modalities share a number of neural structures). As far as this point is concerned, it has been claimed that it is the common organization of the brain that allows us to talk about and appreciate art without using the written or spoken word (Zeki, 2002a, b, 2008). On the basis of this consideration, one might expect certain commonalities in the neural correlates of our aesthetic experiences for different sensory modalities. However, it has also been demonstrated that the processing of the aesthetic aspects of stimuli are related to the more general characteristics of information processing that are specific for a given sensory modality. Therefore, considering that these characteristics are not necessarily the same for different sensory modalities, one might also expect there to be some important differences in the neural substrates associated with the hedonics experiences elicited by stimuli presented to different sensory systems. The study of the neural correlates of tactile aesthetics might also be useful here when it comes to the development of stimuli that specifically increase the activation of certain brain areas in order to obtain specific effects in both patients and healthy subjects (i.e., increase pleasure, relax, improve positive mood, reduce pain, etc.).

Although the neural correlates of tactile aesthetics have never been directly investigated by researchers, certain important considerations can be drawn from the few studies that have attempted to differentiate the neural correlates of different aspects of tactile information processing. In

⁶ Here another problem is related to the fact that cognitive factors also play an important role in our aesthetic judgments. That is, is it really possible to elicit the same emotions and experiences when people know that what they are touching is only a replica of a 1000-year-old object rather than the real thing?

particular, in Chapter 2 we saw how there are receptor systems in the human skin (CT afferent conductive neural fibers) that appear to code for pleasant touch (e.g., Vallbo & Johansson, 1984; see McGlone et al., 2007; McGlone & Spence, 2010, for reviews). The latter appear to respond vigorously to the slow stroking of the skin (e.g., Bessou, Burgess, Perl, & Taylor, 1971; Iggo, 1960; see also Olausson et al., 2008). Moreover, the results of neuroimaging studies have highlighted the fact that certain brain areas, such as the OFC, respond specifically to “pleasant touch” (as compared to neutral touch), such as the feel of velvet on the skin (Francis et al., 1999; see also McCabe, Rolls, Bilderbeck, & McGlone, 2008, for the report of a top-down effect, due to cognitive manipulations,⁷ on the activation of these areas generated by pleasant stimuli). Despite the importance of these findings, it is worth mentioning that most of those tactile (but more generally multisensory) experiences generated experimentally in fMRI scanners are rather far from what one would consider as pleasurable in an everyday situation (i.e., to get the picture, just imagine yourself as an experimental participant with your head clamped, lying absolutely still in a narrow tube, listening to the extremely loud noise generated by the functioning of the scanner, while some unknown scientist rubs different materials over your thigh). However as we saw in Chapter 2, CT afferents predominantly innervate the hairy part of the skin rather than glabrous parts of the skin, such as the fingertips (e.g., Vallbo & Johansson, 1984). Therefore, while the CT fibers are likely involved in the appreciations of objects such as clothing or within interpersonal tactile stimulation, they are unlikely to intervene in the aesthetic appreciation of haptically explored 3D objects.

Interestingly, different neuroimaging studies have demonstrated that the OFC is involved in the representation of the reward value and of the subjective pleasantness of stimuli (e.g., Rolls, 2000, 2004). In humans, damage to the OFC may result in disinhibited forms of behavior, including swearing, hypersexuality, poor social interaction, compulsive gambling, and excessive alcohol/smoking/drug use (see Beer, Shimamura, & Knight, 2004, for a review). One neuroimaging study has also demonstrated that the degree of activation of participants’ OFC is related to the rated attractiveness of faces as a function of the participant’s sexual orientation (Ishai, 2007; McGlone et al., 2013). That is, this structure (and its link to motor, sensory, and emotional areas of the brain; such as primary sensory cortex, the amygdala, the striatum and nucleus accumbens; e.g., Schoenbaum, Roesch, & Stalnaker, 2006) appears to be the perfect candidate to evaluate the affective value of sensory experiences and initiate a possible reaction to them (e.g., Dickinson & Balleine, 2008).

Taken together, these studies clearly suggest that the OFC plays a very important role in people’s hedonic experiences, regardless of the sensory modality of the eliciting stimuli (e.g., Kringelbach, 2005). Note, however, that different subareas within the OFC might be responsible for the processing of the hedonic aspects of the stimuli in a more modality-specific manner (see Francis et al., 1999). It would be of interest in the future, therefore, to investigate whether the level of activation in the OFC (as well as the specific spatial activation within this structure), and perhaps also in other brain areas that have been shown to be activated by the presentation of pleasant/unpleasant stimuli, correlates with the participants’ ratings regarding the hedonics aspects of different materials/objects/textures that they are required to explore haptically or that are passively presented on their skin (cf. Kringelbach et al., 2003).

⁷ Here the authors used different labels (“Rich moisturizing cream” or “Basic cream”) for exactly the same stimulus applied to the participants’ forearm. These labels affected the participants’ brain activations to the sight of touch as well as the perceived pleasantness of the stimuli.

Other important areas that are likely involved in aesthetic judgments regarding tactile stimuli are those responsible for the initial processing of tactile sensations (such as SI and SII) and those responsible for our memory of tactile stimuli (such as the anterior and ventrolateral prefrontal cortex, the posterior parietal cortex, the perirhinal cortex, the insula, and the lateral occipital complex; see Chapter 5). Indeed, the “beauty” of a given tactile stimulus might be based on its ability to make people recollect more or less explicitly previous pleasurable sensations (see section 12.3.3).

12.6.1 Aesthetics and pleasure

In order to analyze the possible neural correlates of tactile aesthetics, we should consider the fact that one of the purposes of many artistic works is to generate some sort of pleasure (see Arnheim, 1993, for a discussion of this point). As a consequence, the studies that have attempted to investigate the neural correlates of pleasure become important for the topic of tactile, as well as visual or auditory, aesthetics (see Chapter 13, for a discussion of tactile pleasure). Activity in many different brain areas, such as OFC, anterior cingulate cortex, insular cortex, amygdala, and other subcortical brain structures have been reported to code for the occurrence of pleasure in both humans and other animals (e.g., Blood & Zatorre 2001; Kringelbach & Berridge, 2008; Rolls 2005; see Berridge & Kringelbach, 2008, for a review).

As far as the sense of touch is concerned, there are no reports of specific brain areas that, when stimulated, result in the desire for tactile sensations, or rather the experience of pleasant touch. However, the case of a patient affected by multiple sclerosis who showed an obsessive and insatiable desire to touch women’s breasts was reported by Frohman, Frohman, and Moreault (2002). In this case, neuroimaging revealed lesions in the right side of subcortical structures (that is, to the ontogenetically older areas of the human brain).

The involvement of subcortical brain structures in this kind of phenomenon might somehow be taken to support the view that certain aspects of tactile hedonic sensations are linked to the more primitive nature of the sense of touch. Indeed, it has been suggested that the sense of touch provides a means of monitoring biologically vital features of the environment by means of direct contact (e.g., Gregory, 1967; see also George Berkeley, 1709, cited in Chapter 1). It is also important to point out that the fact that cases of altered hedonic sensation elicited by touch alone have rarely been reported in the scientific literature might simply suggest that researchers’ attention has never directly addressed this topic. One should also consider the fact that the majority of research on the neural correlates of pleasant sensations has so far been related to the study of people’s sexual and/or eating behaviors. Note, however, that the sense of touch plays a very important role in both of them (e.g., Krishna & Morrin, 2008; Morris, 1971).

Finally, it is worth mentioning that the brain areas that are activated as a function of the hedonic value of tactile stimuli might vary as a function of people’s expertise. Indeed, it has been shown in previous chapters that those individuals who are expert in certain tasks or games that involve the manipulation of tactile stimuli may exhibit extensive activation of the visual cortex (the “visual” part of the brain) when asked to recognize those stimuli haptically (e.g., Saito, Okada, Honda, Yonekura, & Sadato, 2007; see Chapter 5). Therefore, one might wonder whether certain brain areas are recruited in the aesthetic judgment of tactile stimuli only in those individuals who have been trained to evaluate the hedonic aspects of tactile objects, for example, people who work on the selection of fabrics for the fashion/clothing industry (see Binns, 1926, 1934, 1937), art collectors, or curators working in museums.

12.7 Conclusions

The review of the literature on tactile aesthetics presented in this chapter clearly demonstrates that despite the fact that the sense of touch has been exploited by many artists over the centuries for their representative purposes, very little scientific research has been conducted on this topic. This scarcity of academic studies related to the more hedonic aspects of touch might, at least in part, result from a lack of an appropriate and commonly shared language for describing tactile sensations (and thus tactile aesthetics; see Diaconu, 2006; Guest et al., 2011; Spence & Gallace, 2008). Surprisingly, it is still rather unclear what kind of materials, textures, shapes, and objects people like to touch and which not (though see Picard et al., 2003).

From the review of the literature reported here, we believe that several different factors will likely contribute to an aesthetic of touch. In particular, some general principles of perception, such as the Gestalt laws, should be of importance for tactile as well as visual hedonic experiences (see Chapter 3). Those tactile stimuli that are intended to generate a pleasurable experience should likely also embody both an abstraction and an amplification of reality. That is, the “beauty” of touch might be related to stimuli that: (1) remind us, although this does not need to be explicit, of previously experienced pleasant tactile sensations; (2) are naturally selected to improve our well-being and the survival of the species (e.g., Harlow & Zimmerman, 1959). As a consequence, warm and soft sensations that perhaps implicitly remind us of our early experience in the womb (think a hot bath) or the contact with our mother’s body will likely be considered pleasant (cf. Dissanayake, 2001). We think that, from the point of view of an aesthetics of touch, the use of the adjective “beautiful” should be considered for these sensations (see Coleman, 1965).

The evidence reviewed here has also revealed the presence of a number of potentially important differences between tactile and visual aesthetics. In particular, tactile aesthetics appear to imply a more intimate and active experience, related to the way in which we move our body in space and therefore to the connection between tactile and motor systems, of objects than that elicited by means of visual stimuli (cf. Sachs, 1988; see also Jansson-Boyd & Marlow, 2007, for evidence that tactile information can affect aesthetic evaluation of visually presented stimuli). That is, the more primitive and active nature of touch seems to generate hedonic experiences that are strongly linked to bodily sensations and emotions (see Ellis, 1936; Gallace & Spence, 2010b; Montagu, 1971). These aspects of tactile aesthetics, together with the empirical observation that tactile sensations are experienced before visual perception (e.g., Atkinson & Braddick, 1982; Bernhardt, 1987), might be taken to support the provocative suggestion that visual aesthetics builds upon our early development of tactile aesthetics. Of course, this suggestion might need a great deal of empirical research in order to be verified.

As far as the active aspect of tactile aesthetics is concerned, one may easily note that the appreciation of tactile stimuli often implies a “desire (or curiosity) to touch”; this might itself be taken to constitute an important part of our aesthetic experience of haptically explored stimuli. Note that the impressive success of touch-screen devices (such as the iPod Touch from Apple) in recent years is probably linked with the inner desire of humans to actively touch, hold, and manipulate those objects that we regularly use (see Chapter 9).

The present review also highlights the fact that the neural correlates of tactile aesthetics have been very little investigated by neuroscientists. The scarce evidence summarized in this chapter suggests that certain brain areas, such as the OFC, might play a very important role in our hedonic experience of touch (e.g., Rolls et al., 2003). We would also like to suggest that a number of brain structures, such as those responsible for the more general perception of pleasure in humans (e.g., Berridge & Kringelbach, 2008; Blood & Zatorre 2001) might be involved (to a certain degree) in

the generation of hedonic experiences elicited by tactile as well as visual and multisensory forms of stimulation. Finally, the somehow “primitive” nature of the tactile modality (as compared to the visual modality) might suggest a role for certain subcortical brain structures (involved in physiological and emotional responses to the stimuli) in people’s aesthetic responses to touch.

In this chapter, we have attempted to highlight the fact that tactile aesthetics constitutes an important topic, one that deserves the attention of scientists in the years to come. Indeed, this topic is not only of theoretical interest, but also offers important insights to many different applied contexts. Understanding what makes an object/texture beautiful to touch, is certainly helpful if one’s aim is to create environments that enhance the well-being and mood of those who live there. Similarly, the study of tactile aesthetics might also be helpful for those fashion designers trying to match the sensations elicited by the materials that they use for their clothing with the particular mood and feeling of people who are supposed to wear them (e.g., Fiore, Moreno, & Kimble, 1996; cf. Workman & Caldwell, 2007; see also Postrel, 2004; Quinn, 2012). Finally, the study of tactile aesthetics might be useful for favoring the appreciation of art contents by visually impaired individuals (e.g., Raffray, 1988; Spence & Gallace, 2008).

Touch in the bedroom: The role of touch in sexual behavior

There is a possibility of developing erotic materials for yourself that would allow you to create a partner of certain dimensions and qualities, the partner saying certain things in that interaction, certain things happening in that interaction.

(Julia Heiman, director of the Kinsey Institute for Research in Sex, Gender and Reproduction at Indiana University, Bloomington, IN, 2006)

13.1 Introduction

When it comes to sexual relations, the role of touch appears indubitable. It is difficult to imagine sexual behaviors that do not involve some forms of proprioceptive and tactile content and certainly the lack of this information would make most of our experiences in this domain much less satisfying (see Bors & Comarr, 1960; Sipski & Alexander, 1992). Sexual pleasure, and orgasm, in particular, are strongly related to tactile stimulation, even if cases of orgasms occurring without physical stimulation of the body have occasionally been reported in the literature (see Komisaruk, Whipple, Nasserzadeh, & Beyer-Flores, 2010). Note also that in both animals and humans it is undoubtedly the interaction between sensations from different modalities that contribute most to the experience of sexual pleasure (see Fletcher & Lindsay, 1968, for evidence showing that sexual behavior in animals is typically triggered by signals from several different senses). That said, it should be borne in mind that those situations in which tactile processing is somehow defective are also likely to be those that have a more detrimental effect on people's sexual behavior. This might be the case for the complete lack or reduction of tactile sensations (e.g., as a consequence of spinal cord injury, peripheral nerve injury, peripheral neuropathy, or sex reassignment procedures; e.g., Sohn & Exner, 2008), abnormal increases or decreases in tactile sensitivity in certain areas of the skin surface, or the presence of allodynia (the perception of pain resulting from normal tactile stimulation), such as in vulvodynia or vulvar vestibulitis (e.g., Bohl, 1998; Pukall, Strigo, Binik, Amsel, Khalifé, & Bushnell, 2005).

Even if tactile stimuli constitute particularly effective means of giving rise to sexual arousal, it should be noted that the "arousing capability" of tactile contact is not simply related to the intrinsic "aedonic" or "sexual" value of these kinds of stimuli per se. That is, it is the context (physiological, cultural, cognitive, and perceptual) in which the tactile stimulation occurs, as well as all of the other stimuli occurring at the same time in other sensory modalities that are likely to affect our sexual experiences. This might result in extremely diverse attributions of sexual values to the very

same situation in different circumstances and by different individuals. For example, even tickling, pain, or sensations elicited by sports activities have been reported by certain individuals to result in sexual arousal and even orgasm (e.g., Herbenick & Fortenberry, 2011; Meston & Gorzalka, 1995, 1996; Pollok, Krause, Legrain, Ploner, Freynhagen, Melchior, & Schnitzle, 2010; see also Bin Saif, Papoiu, Banari, McGlone, Kwatra, Chan, & Yosipovitch, 2012, for the pleasure associated with scratching an itch¹).

If one's aim is to understand the role of touch in our sexual behavior, and/or to reproduce those conditions of tactile stimulation that give rise to sexual pleasure, many different parameters should be considered. In particular, the relative role of different body sites, neural pathways, neurophysiological responses, and cultural factors as well as their mutual relationship must be addressed. In this chapter, we will start by addressing the concept of "erogenous zones" from a cultural, psychological, and physiological perspective.

13.2 The concept of erogenous zones: Cultural, psychological, and physiological perspectives

An erogenous zone can be defined as an area of the human body, whose stimulation may result in sexual arousal. Here it is important to note that in certain individuals the stimulation of these body parts might be sufficient to induce orgasm without the need for any genital contact (see also Komisaruk & Whipple, 1998, 2005, for the occurrence of orgasms in spinal cord-injured patients). A number of specific bodily zones have been found to be associated with sexual responses. These include areas of the genitals, the foreskin and corona of the glans penis, the clitoris, the vulva and perianal skin, and the lips. Many other sites on the body can also be considered erogenous but their relationship with sexual behavior and arousal varies from one individual to the next. For example, one study reported that 81.5% of women and 51.7% of men find that the stimulation of their nipples/breasts causes or enhances their sexual arousal, while 7.2% of women and 7.5% of men find that the same stimulation actually decreases it (Levin & Meston, 2006). Earlobes can also be considered an important erogenous zone, especially when it is considered that some women report high levels of arousal and even, on occasion, orgasm after the stimulation of this part of the body (an effect that might be related to the neural transmission along the vagal nerve; see Komisaruk, Whipple, Crawford, Grimes, Liu, Kalin, & Mosier, 2004).

Even if research in this field has only just begun to provide useful scientific evidence, one might reasonably think that the very concept of "erogenous zones" depends on the complex interaction between a number of factors, comprising cultural, psychological, and physiological variables. For example, it is cultural factors that contribute most to defining those areas of another person's body that one can touch in a given context and those which one cannot (Barnlund, 1975; Heslin & Alper, 1983). For example, Barnlund asked a number of North American and Japanese participants what areas of the body had recently been touched by friends of the opposite sex, friends of the same sex, their mother, and their father. The results of this study clearly demonstrated that the areas available for touch are more restricted in Japan than in the United States (see Figure 13.1). Even if no study has, as yet, been reported on this topic, one might expect that similar intercultural effects would also affect the perception of which body parts result (excluding the genitals) in sexual arousal and which not. This might be the case, for example, of the much more important

¹ See <<http://www.thesun.co.uk/sol/homepage/features/4078650/.html>>; downloaded on November 6, 2012, for the interest of popular media on topics related to the neural mechanisms of pleasure in humans.

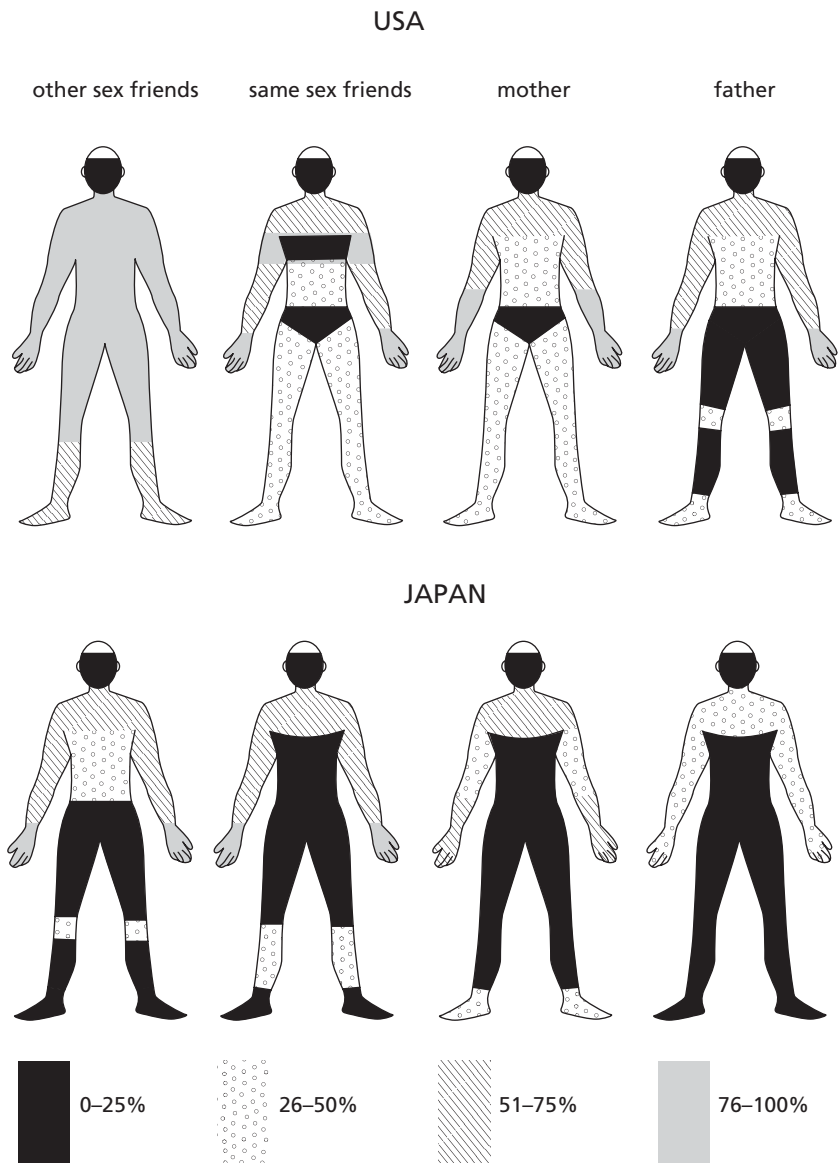


Fig. 13.1 Areas of the body that had recently been touched by different people and in two different cultures in Barnlund's (1975) study.

arousing role played by the nape of the neck in Japanese as compared to European culture (something that also justifies the observation that Japanese Geisha used to wear white makeup on their face but not on the back of their neck; <<http://en.wikipedia.org/wiki/Geisha>>; downloaded on March 23, 2012).

It is also important to note here that the way in which our brain links together stimuli and experiences certainly contributes to explaining why it is that the stimulation of a particular part of the body is considered as sexually arousing by certain individuals but not by others. Furthermore,

in the majority of cases, it is not the mere stimulation of a certain body part (or area of skin) that elicits sexual arousal but rather the specific way in which that tactile stimulation occurs as well as its multisensory context. That is, a single tactile contact with the genitals might not be as effective in inducing a pleasant experience as the slow stroking of the skin (the latter likely activating a particular class of neural fibers) within a given context.

As far as the genitals are concerned, a number of animal studies have attempted to identify those differences that exist between their neural innervation and that seen in other areas of the body. In particular, electrophysiological and morphological studies in both male and female rats have demonstrated that the type of receptors and the physiological responses of the system innervating the external genitalia are unlike those found elsewhere in the skin (e.g., Berkley & Hubscher 1995; Johnson 1988; Johnson & Halata, 1991; Johnson & Murray, 1992). These differences (also found in humans) are likely to give rise to the different qualities of tactile sensations reported by people when these parts of the body are stimulated.

Animal studies have shown that penile tissue possesses characteristics of both skin and of viscera and in particular the glans penis contains a high number of free nerve endings innervated by A δ fibers (Halata & Munger, 1986; Johnson & Halata, 1991; see Chapter 2). By contrast, very few corpuscular receptors (see Chapter 2) can be found on this particular part of the body. As a result of this neuroanatomy, the human glans penis exhibits virtually no sensitivity to fine touch and can only perceive deep pressure and pain at a high threshold (i.e., “protopathic” sensations; e.g., Halata & Munger, 1986; see Von Frey, 1894, for an early report of this poor sensitivity).



Fig. 13.2 Portrait of Sir Henry Head (1861–1940).

² This observation perhaps can be taken to offer some empirical support to the often reported popular claim that the tactile sensations during oral sex can be enhanced by first sucking on a mint (see <<http://www.mademan.com/mm/10-erotic-sex-tips.html>>; downloaded on October 25, 2012).

Despite the low sensitivity of the glans, the ridged band of the prepuce contains ten times more encapsulated touch receptors (Meissner's corpuscles, mucocutaneous receptors, genital corpuscles, and Pacinian corpuscles) than the glans penis (e.g., Halata & Munger, 1986), transducing more fine tactile information. Note that the male prepuce has been shown to play an important role in normal copulatory function, and its surgical removal would appear to disturb normal copulatory behavior in male mammals and result in altered patterns of sexual behavior in animals (e.g., Laumann, Masi, & Zuckerman, 1997; see also Cold & McGrath, 1999). The difference between the sensations that result from the stimulation of different parts of the penis and their reciprocal interactions have been clearly described by the famous neurologist Sir Henry Head (see Figure 13.2) in one of the first reports to have been published on this matter (see Rivers & Head, 1908). Note that Head performed a number of pioneering experiments (comprising the surgical sectioning of some of the peripheral nerves in his left arm and hand) using himself as a subject in order to determine which nerves were responsible for areas of sensation and to create a map of how sensory abilities differed across the body surface. Here is Rivers and Head's original report: "When, therefore, it [the tip of the penis] was dipped into water at 40° C, no sensation of heat was produced, but H. [Head] experienced an unusually disagreeable sensation of pain. When the water was raised to 45° C, this was to a great extent displaced by a vivid sensation of cold. But, as soon as the water covered the corona without reaching the foreskin, both cold and pain disappeared, giving place to an exquisitely pleasant sensation of heat" (Rivers & Head, 1908, p. 444; see also Geirsson, 1993, for evidence that the thermal sensitivity of the genitals is also affected by chemicals such as menthol²).

The external female genitalia are more richly innervated than other body parts. The inner two-thirds of the vagina is only innervated by pain receptors, but the outer third, in particular, between the vaginal wall and the bladder, is innervated by the Merkel tactile discs (Krantz, 1958), which respond to steady pressure (Vallbo & Hagbarth, 1968; see Chapter 2). The mons veneris, labia majora, labia minora, and the clitoris are innervated by Meissner corpuscles, Merkel tactile discs, Pacinian corpuscles, Ruffinian corpuscles, and pain receptors (Krantz, 1958; Yamada, 1951; see Figure 13.3, for a representation of the human genitalia). Studies of the effects of mechanical

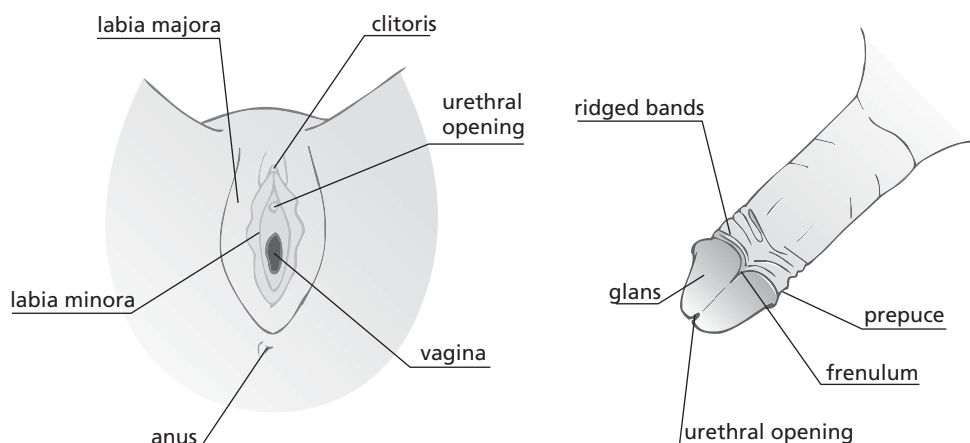


Fig. 13.3 View of the human genitalia in women and men.

stimulation to the genital region suggest that different areas of the genitalia respond to different types of stimulation. This also depends on the fact that the external genitals contain high- and low-threshold slowly adapting (SA) receptors as well as low-threshold rapidly adapting (RA) receptors. More specifically, the vagina primarily contains RA receptors (although some SA receptors also respond to deep pressure). By contrast, the cervix contains SA receptors that respond to pressure and the movement of stimuli across it (Cueva-Rolon, Munoz-Martinez, Delgado-Lezama, & Raya, 1994).

Genital afferents signal multiple sensory qualities of the stimuli (pressure, temperature, pain, friction) and travel via multiple pathways to reach subcortical structures such as the brainstem, midbrain, and the somatosensory and visceral thalamus (Everaert et al., 2010; Hubscher & Johnson, 2003; Hubscher, Reed, Kaddumi, Armstrong, & Johnson, 2010; Komisaruk et al., 1996). From these relay centers, information from the genitals can reach different brain areas and, in particular, the somatosensory cortices and the insula areas. A number of studies have highlighted the presence of an association between the tactile sensitivity recorded at the penis and vagina and dysfunctions in sexual behavior. For example, men who suffer from erectile problems have been reported to have reduced tactile sensitivity as compared to those with no erection difficulties (Morrissette, Goldstein, Raskin, & Rowland, 1999; Rowland, 1998; Rowland, Haensel, Blom, & Slob, 1993; Rowland, Leentvaar, Blom, & Slob, 1991).

As briefly mentioned earlier, an alteration of sexual function has sometimes been reported in those patients undergoing circumcision surgery procedures (the removal of some or all of the foreskin from the penis) for the correction of a penile problem. Follow-up studies performed on such patients have revealed that a high percentage (from 27% to 64%; e.g., Coursey, Morey, McAninch, Summerton, Secrest, White, et al., 2001; Shen, Chen, Zhu, Wan, & Chen, 2004) of circumcised patients reported no improvement after surgery, together with a decrease in penile sensitivity, or a reduction in erectile function.

Interestingly, oversensitivity of the genitals also results in sexual problems. More specifically, several reports would seem to suggest that penile hypersensitivity is one of the primary underlying causes of premature ejaculation, a condition that is thought to affect anywhere between 30% and 75% of the male population (see Wyllie & Hellstrom, 2010).

As far as the female genitals are concerned, a number of studies have highlighted the presence of an association between sexual dysfunction and a decrease in tactile sensitivity. In particular, a study by Gruenwald and colleagues (2007) revealed that tactile and thermal sensitivity at the level of the vagina and clitoris were measured in women affected by multiple sclerosis (a group of patients thought to be at higher risk for developing sexual difficulties). They found a reduction of tactile vibratory sensitivity, especially at the level of the clitoris, correlated with the presence of sexual dysfunction as measured by the sexual function index (FSFI) questionnaire (comprising questions such as: "Over the past 4 weeks, how satisfied were you with your ability to reach orgasm (climax) during sexual activity or intercourse?"; Rosen, Brown, Heiman, Leiblum, Meston, Shabsigh, et al., 2000). Similarly, diminished tactile sensitivity has been shown to impair women's orgasm from penile-vaginal intercourse (but not from other sexual activities; Brody, Houde, & Hess, 2010).

Interestingly, the association between tactile sensitivity and dysfunctions of sexual behavior is not only restricted to the genitals. Frohlich and Meston (2005a), for example, investigated tactile sensitivity on the distal portion of the index finger of the dominant hand and on the lower lip in women with female sexual arousal disorder (reporting lack of vaginal lubrication 50–100% of the time, present over the past 6 months) and in normally functioning women. They found that tactile sensitivity as measured at fingertip negatively correlated with the severity of arousal dysfunction

(measured along the scales of sexual desire, arousal, lubrication, orgasm, satisfaction, pain). That is, the lower the sensitivity, the more severe was the sexual dysfunction (see also Frohlich & Meston, 2005b).

A smaller number of studies have investigated the physiological and sensory characteristics of erogenous areas of the body outside of the genital regions. As far as tactile processing is concerned, we have already seen in Chapter 2 that sensitivity varies over different areas of the skin (e.g., Weinstein, 1968). Within this representation of sensitivity over the body surface, erogenous zones, such as the breasts and lips would seem to exhibit higher levels of tactile sensitivity, whereas others, such as the inner thigh or belly (areas that are closer to the genitals than other body areas) have much lower sensitivities (e.g., Weinstein, 1968). Note also that breast sensitivity would seem to be higher in women than in men, a result that is seemingly compatible with the reports that the stimulation of this area of the body is considered more arousing for women than for men (Levin & Meston, 2006; see also Levin, 2006). Other areas of the body that are considered more erogenous in some people and cultures than in others, such as the feet or the back of the neck (see Giannini, Colapietro, Slaby, Melemis, & Bowman, 1998) have average levels of tactile sensitivity as compared to other body sites (see Weinstein, 1968). Taken together, these data would appear to suggest that tactile sensitivity per se is not sufficient to characterize the arousing capability of one area as compared to another. Alternatively, the location of the brain area where tactile sensations are represented might be a factor that affects the definition of erogenous zones and their value in terms of sexual arousal. That is, Many people find the stimulation of their feet (think toe sucking) to be erotic, and that may be because the brain region responding to sensations from the genitals within the somatosensory cortex is located next to the region representing the foot (e.g., Komisaruk, Wise, Frangos, Liu, Allen, & Brody, 2011; Penfield & Boldrey, 1937; though see Michels, Mehnert, Boy, Schurch, & Kollias, 2010, for evidence suggesting a different representation of the clitoris as compared to that initially suggested by Penfield and Boldrey; see Figure 2.3).

A number of older studies tried to reveal the presence of physiological differences between erogenous body areas such as the lips, the perianal region, the areola and nipples, and other parts of the skin (e.g., Cathcart, Gairns, & Garven, 1958). However, the evidence from these studies has proved to be rather controversial thus making any inference regarding the presence of peculiarities in erogenous zones purely speculative (see Winklermann, 1959, for a discussion of this point).

One important question to be addressed here is whether tactile sexual stimuli can be referred to positions of the body where there are no receptors (or even when there isn't a body part to be stimulated). That is, can erogenous areas be transferred to other areas of the body or even to their artificial counterparts? Can this transfer occur towards body parts and genitals that appear to be different from our own?³ Can people really make love by means of another body or by means of an avatar? This question becomes relevant if one's aim is to reproduce tactile sensations arising from virtual bodies or artificial prosthesis. This might, for example, be the case for patients following amputation, spinal cord injury (e.g., Borisoff, Elliott, Hocaloski, & Birch, 2010), patients undergoing sex reassignment procedures (e.g., Namba, Sugiyama, Yamashita, Tokuyama, Hasegawa, & Kimata, 2008; Selvaggi, Monstrey, Ceulemans, T'Sjoen, De Cuypere, & Hoebeke 2007), and patients suffering from erectile dysfunction (e.g., Rodríguez Faba, Martín Benito,

³ Here one might also think about the possibility of changing the appearance of genitals by means of some illusions seen in Chapters 3 and 8 (see, for example, the "Pinocchio" or the RHI illusion).

Escaf Barmadah, Rodríguez Martínez, Jalón Monzón, & Regadera Sejas, 2004). Moreover, referring tactile sensation to external locations might also increase the sense of presence of virtual sex simulations within artificial virtual environments.

As we have already seen in Chapter 8, under certain conditions of stimulus presentation, people sometimes attribute tactile stimuli to a rubber hand or to an artificial limb (e.g., Makin et al., 2008). Similarly, the literature on tactile information processing has demonstrated that the stimulation of two alternative locations can be effective in eliciting a tactile percept in an area of the body (located between the two stimuli) that has not been actually stimulated or even outside the bounds of the physical body (e.g., Miyazaki, Hirashima, & Nozaki, 2010). At present, no published study has yet addressed the question of whether or not these phenomena might also occur for the genitals or other erogenous body sites. However, considering that other experimental manipulations, such as those eliciting the crossed hand effect, have been reported to be successful when the testicles were crossed (see Ponzo, 1910) one might reasonably think that other phenomena also extend to this body region. In that case, the reproduction of tactile sensations on artificial and/or virtual genitals (being they prosthetic, transplanted organs, or even dildoes) should be a viable possibility for many different applications.

A number of studies have reported the presence of phantom sensations (e.g., sensations referred to amputated organs) referred to the penis (e.g., Fisher, 1999; Namba, Sugiyama, Yamashita, Tokuyama, Hasegawa, & Kimata, 2008; Ramachandran & McGeoch, 2007, 2008). Note, however, that only a small number of articles have examined what body areas, when stimulated, produce such phantom experiences in the absent penis. The reports of lower limb amputees suggest that defecation, tactile foot stimulation, and sexual foreplay may result in such referred sensations (e.g., Ramachandran, 1998). These observations might be taken to suggest a medial-to-lateral reorganization within the somatosensory cortex after amputation. In fact, the genital region, rectum and anus are found medially to the lower limb within the sensory homunculus (see Aglioti et al., 1994).

Interestingly, phantom sensations regarding the genitals do not only occur as a consequence of amputation. In fact, it has been shown that over 60% of a group of female-to-male transsexuals reported the presence of phantom penises (including phantom erections) regardless of whether a phalloplasty operation had already been performed (Ramachandran & McGeoch, 2008). This data, then, suggests that the actual anatomy is not so relevant to the attribution of sexual sensation to a given body site. Note however, that the study by Ramachandran and McGeoch was performed on a specific population of individuals, namely transsexuals, and that possible differences in hard-wired neural mechanisms might be important in terms of explaining individual differences in gender-specific body image.

Further investigations will be needed in order to verify whether tactile sensations can be referred to virtual/artificial genitals, and their effect on the cognitive and neural representation of the body. This question would be even more interesting from both a theoretical and applied point of view considering opposite-gender attributions of virtual genitals. That is, how and to what extent does the representation of the female body change (if at all) after eliciting the illusion of owning a penis?

13.3 Touch-induced hormone release

Over the course of the last decade, a number of studies have reported the presence of an association between hormonal responses and tactile stimulation, in both animals and humans. In particular, it has been demonstrated that the release of oxytocin is increased by thermal and tactile

somatosensory stimuli (e.g., Dunbar, 2008; see also Ishak, Kahloon, & Fakhry, 2011). As far as sexual behavior is concerned, studies on this topic have highlighted how when the genitals or erogenous zones, such as the nipples, are sexually stimulated, oxytocin levels increase and facilitate sexual arousal and receptivity (e.g., Carmichael, Humbert, Diken, Palmisano, Greenleaf, & Davidson, 1987; Carter, 1992). For example, vagino-cervical stimulation results in the release of luteinizing hormone, prolactin, and oxytocin, as well as resulting in a number of physiological (heart rate increase, blood pressure increase, pupil dilatation) and behavioral (e.g., lordosis, analgesia; see Whipple & Komisaruk, 1988, for the analgesic effect of genital stimulation) changes (see Komisaruk, 1990; Komisaruk & Whipple, 1998, for reviews). Here it is relevant to highlight the fact that not only is the stimulation of the genitals capable of affecting hormonal responses but also the stimulation of other body parts can result in these neurophysiological effects. In particular, the stimulation of the female erogenous areas, such as the nipples, results in the release of both oxytocin and prolactin (e.g., Komisaruk & Steinman, 1986). The similarity between the effect of vagino-cervical and nipple stimulation in the hormonal responses of females has sometimes been taken to explain the reports of orgasm solely elicited by nipple stimulation (Komisaruk & Whipple, 1998).

It is also relevant to note here that not only do tactile stimuli affect hormonal responses but tactile sensitivity, including genital sensitivity, can also be influenced by hormone release (e.g., Burris, Gracely, Carter, Sherins, & Davidson, 1991; Carter, 1992; Komisaruk, 1978). For example, a number of studies have demonstrated that those hormones known to affect sexual arousal in females will also affect their tactile sensitivity. That is, normal estrogen levels are required to produce adequate vaginal lubrication (Bachmann, 1995). However, estrogen treatment has also been found to affect tactile sensitivity in both rats and canaries (Bereiter & Barker, 1975; Bereiter, Stanford, & Barker, 1980; Hinde & Steele, 1964; Kow & Pfaff, 1973). The tactile information processing system is likely more closely linked to the neural systems that support hormonal responses than to any other sensory system in the brain (probably with the sole exception of the chemical senses; e.g., Wacker & Ludwig, 2012). That is certainly one of the reasons why tactile stimulation is so important in bonding and sexual behaviors in animals as well as in humans (see Chapter 7).

A relatively less extensive scientific literature has investigated the relationship between hormone release and tactile genital stimulation in males. Most of these studies have been performed on animal models showing, for example, that the electrical stimulation of the dorsal penile nerve in rats (presumed to represent an equivalent of tactile stimulation during copulation), as well as tactile stimulation of the glans penis by a paintbrush, are effective in producing excitation in nearly 50% of oxytocin-containing cells in the paraventricular nucleus of the thalamus (Yanagimoto et al., 1996; see also Andersson, 2001). Similarly, slight elevations in oxytocin levels have been measured following pre-ejaculatory behaviors, such as mounting in male rabbits and during sexual arousal in humans (e.g., Carmichael, Humbert, Diken, Palmisano, Greenleaf, & Davidson, 1987; Stoneham, Everitt, Hansen, Lightman, & Todd, 1985).

Here it is worth noting that hormone release, or changes in hormone levels, are not only induced by the sexual stimulation of the genitals. In particular, saliva cortisol and insulin levels decrease significantly after touch massage in healthy participants (e.g., Lindgren, Rundgren, Winsö, Lehtipalo, Wiklund, Karlsson, Stenlund, et al., 2010; cf. Feldman, 2012). Similarly, Swedish massage therapy (compared to light touch alone) has been reported to cause a decrease in arginine-vasopressin and cortisol (e.g., Rapaport, Schettler, & Bresee, 2010). Even if no direct evidence has been reported so far, one might reasonably hypothesize that the tactile rubbing of different body parts that may occur during foreplay or sexual intercourse might contribute to the hormonal

effects attributed to sexual behavior. That is, hormonal changes during sexual behavior are likely due to the occurrence of different kinds of tactile (as well as multisensory) stimulation of the body rather than to genital stimulation *per se*.

It is important to highlight here that the relationship between touch and hormones is bidirectional. In fact a number of studies have clearly suggested that hormone release is effective in modulating tactile sensitivity. For example, Masters and Johnson (1966), in one of the first extended studies on human sexual behavior, described a post-orgasmic refractory period in men. This is defined as the period of time immediately after orgasm in which men experience tactile hypersensitivity in the glans of the penis to the extent that it causes stimulation to be aversive (Yilmaz & Aksu, 2000). Earlier studies on this topic excluded the presence of such phenomenon in women (“the female has no such refractory period”; Master & Johnson, 1966, p. 283), and even more recent reviews on the topic took this claim for granted (e.g., Hyde, DeLamater, & Byers, 2009; Rathus, Nevid, Fichner-Rathus, & Herold, 2009). By contrast, recent evidence from studies that have made use of questionnaire procedures would appear to suggest that the majority of women also experience clitoral hypersensitivity and aversiveness to further clitoral stimulation after orgasm (e.g., Humphries & Cioe, 2009). This phenomenon in men has been attributed to the release of prolactin immediately following orgasm (Kruger et al., 2003). In fact, increases in the level of prolactin in the blood can be considered a regulatory mechanism that helps to control sexual libido and sexual behavior (Exton et al., 2000; Kruger et al., 2003; Kruger, Hartmann, & Schedlowski, 2005; see also Schradin & Anzenberger, 1999, for the observation that the release of prolactin induces “paternal” behavior in male animals).

Other evidence related to the role of hormones in modulating tactile sensitivity comes from the studies that have investigated the sensitivity of certain erogenous zones during different periods of time in men and women. These studies have demonstrated that breast sensitivity does not differ between boys and girls prior to puberty, but women’s breasts became much more sensitive after puberty. Moreover, in women, this sensitivity undergoes rhythmic changes during the menstrual cycle, with maximal sensitivity just after mid-cycle and at menstruation (Robinson & Short, 1977). In women, other changes occur during pregnancy with the breasts becoming relatively insensitive (the two-point discrimination distance becomes greater than the nipple or areolar diameter) during the latter weeks of pregnancy and an abrupt increase in sensitivity is seen 24 hours after parturition. These changes are likely driven by variations in the concentration of hormones such as prolactin and estrogens (e.g., Robinson & Short, 1977; see Weis & Hausmann, 2009, for the variation of hormone release during the menstrual cycle). In summary, touch appears to be strongly linked with mechanisms of hormone release in the brain.

13.4 On the role of C fibers in sexual pleasure

In Chapter 2, we briefly highlighted the mechanisms of transduction and conduction of the signals arising from the skin surface. The role of different pathways in transmitting tactile information from the periphery of the body to the central neural system was also discussed. While describing the more social aspects of touch (see Chapter 7), evidence was reported regarding the important role played by the CT afferents in mediating the more pleasant aspects of tactile perception. In particular, we have seen how these fibers respond particularly vigorously to the slow stroking of the skin, a stimulus that somehow resembles a caress (e.g., Bessou, Burgess, Perl, & Taylor, 1971; Iggo, 1960; see also Olausson et al., 2008). C afferent fibers predominantly innervate the hairy rather than the glabrous parts of the skin (e.g., Vallbo & Johansson, 1984). As far as sexual behavior is concerned, it is important to note that the genitals are highly innervated by

the conventional C fibers but that no studies have so far reported the presence of CT afferents in the genitals (see Liu et al., 2007, for a negative report regarding the existence of such afferents in the genitals of animals). This, despite the fact that one can easily image that their role in sexual behavior is likely to be of great importance.

One might reasonably think that if CT fibers play an important role in conveying the more pleasant aspects of tactile stimulation, a reduction of the signals carried from these afferents might be expected to have a detrimental effect on a person's sexual behavior. A recent study investigated a group of patients affected by a heritable disorder associated with a mutation affecting the nerve growth factor beta gene which results in a reduction in the density of thin and unmyelinated nerve fibers, including CT afferents (Morrison, Löken, Minde, Wessberg, Perini, Nennesmo, & Olausson, 2011). The results of this study revealed that these patients perceived a gentle, slow stroking of the arm, an optimal stimulus for eliciting CT afferent responses, as less pleasant than did a group of healthy control participants. Interestingly, the authors also reported that the patients' evaluation of the pleasantness of observed stimulation was reduced. Unfortunately, no data were reported concerning the relationship between the patients' evaluation of pleasant tactile stimuli and their evaluation of sexual experiences. However, the participants in this study had to answer a questionnaire that evaluated the affective aspect of interpersonal touch behavior in social situations, particularly with reference to opposite-sex relationships (e.g., items on the questionnaire required people to rate their degree of agreement regarding statements such as "I enjoy touching my girlfriend/boyfriend when greeting that person"). No significant differences were reported in the questionnaire rating suggesting that patients did not differ from controls in their self-reporting of how they perceived and used touch in social relations. Once again, while C fibers do not appear to affect the way in which people perceive their social relationship with their partner, the question of the role of a dysfunction in C afferent fibers in affecting sexual pleasure still remains open. Note also that the large majority (if not all) of the studies that have addressed this important topic to date have made use of questionnaires (likely affected by people's beliefs and expectations; e.g., Rosenthal, 1966; see also Chapter 9, section 9.7, for a critical view on the use of questionnaire procedures) rather than of more reliable forms of behavioral or neural responses, thus making any interpretation of their results even more difficult.

Even if no direct evidence has been reported so far concerning the role of CT afferent fibers on sexual dysfunction, a relationship has been found between a lack of tactile non-erotic stimulation and disorders of sexual behavior, that might be mediated by these tactile fibers. In particular, it has been reported that children who are deemed to masturbate excessively often lack parental non-sexual tactile stimulation. The reinstatement of affectionate non-sexual tactile contact by the parent can serve to reduce this problem (McCray, 1978). Given that social non-sexual contact would seem to involve the activation of CT fibers (e.g., Morrison, Björnsdotter, & Olausson, 2011; though note that no evidence has been provided so far on their involvement in sexual functions), one might speculate that a reduction in the activation of these fibers result into a compensatory desire for tactile sexual stimulation. These effects might be mediated by the hormonal responses likely generated by the activation of tactile-fibers (not necessarily CT) in both parental and sexual contacts.

A number of studies have investigated the target of CT fibers within the central nervous system. In particular, the results of functional neuroimaging studies suggest that C fibers have a primary cortical target in the posterior insular cortex (Olausson et al., 2002, 2008), an area of the brain that is strongly interconnected with the amygdala, hypothalamus, orbitofrontal cortex, and homeostatic regions of the brainstem (Augustine, 1996; Craig, 2002, 2003; Craig et al., 2000; Olausson

et al., 2002, 2008). That is, the system responsible for pleasant touch and that is activated by the stimulation of C fibers is likely to be part of a complex network associated with the maintenance of physical and social well-being in humans (Björnsdotter, Morrison, & Olausson, 2010). Note, however, that no study has ever directly investigated the spinocortical projections of CT afferents in humans (see Andrew, 2010, for evidence showing that in rats the equivalent of these fibers project to lamina I spinoparabrachial neurons).

The insula, and, in particular, its middle and posterior divisions would appear to be implicated in the processing of neural information giving rise to genital sensitivity. This involvement was observed upon dorsal penile (Makela et al., 2003) and clitoral nerve stimulation (Michels et al., 2010), during tactile genital stimulation in a sexual context (Georgiadis et al., 2006, 2010; Georgiadis & Holstege, 2005) and during stimulation of the vestibulum (an area around the vaginal opening) that wasn't intended to be erotic (Pukall et al., 2005). However, middle and posterior insula responses were much stronger in those participants who perceived the vestibular stimulation as painful, while during intentionally non-erotic genital stimulation such insular activation was absent (Kell et al., 2005; Komisaruk et al., 2011). When taken together, these findings would appear to support the view that the posterior insula is an important area for the detailed encoding of salient or behaviorally relevant information coming from the skin surface. This might be the case of noxious stimulation (that is also conducted by those fibers; Henderson, Rubin, & Macefield, 2011), pleasant touch (Björnsdotter, Löken, Olausson, Vallbo, & Wessberg, 2009), and/or responses related to sexual behavior (e.g., Cacioppo, Bianchi-Demicheli, Frum, Pfaus, & Lewis, 2012).

Interestingly, not only did the direct stimulation of the genitals give rise to insular cortex activation, penile tumescence derived from visual input or imagery (known as psychogenic erections) without any form of somatosensory stimulation, correlated with activity in the middle and especially the posterior insula (Arnoult et al., 2002; Moulrier et al., 2006; Mouras et al., 2008; Redout et al., 2000). In addition, it has been established that sexual tactile penile stimulation elicited greater activity in the posterior insula than similar stimulation on the clitoris (Georgiadis, Reinders, Paans, Renken, & Kortekaas, 2009). Such observations would therefore appear to suggest that the posterior insula reacts to bodily changes related to sexual behavior (such as genital engorgement) more than to the tactile stimulation per se. Note, however, that studies of the more perceptual aspects of touch have shown that whenever people see a particular region of the body being touched, there is a neural activation of the same areas of the brain involved in codifying tactile information coming from that body position (e.g., Banissy, Cohen, Kadosh, Maus, Walsh, & Ward, 2009; see also Banissy & Ward, 2007, for the link between these phenomena and empathy). That is, even when no direct tactile stimulation is delivered, areas of the brain involved in the processing of tactile information might be activated by visual stimuli (see Keysers et al., 2004; McCabe, Rolls, Bilderbeck, & McGlone, 2008; see also Chapter 7). Whether this phenomenon also extends to the genitals is certainly a relevant question for future research in this field. However, the fact that direct tactile stimulation of the genitals per se might not be essential in terms of eliciting brain activity related to sexual behavior is certainly relevant to the development of virtual or prosthetic genitals for a number of different applications.

13.5 Touch and the central mechanisms of pleasure

Tactile stimulation of the genitals gives rise to the activation of a number of different brain areas within the neocortex. The studies that have addressed the cortical representation of the penis have yielded somewhat mixed results (Bradley, Farrell, & Ojemann, 1998; Michels et al., 2010). In

particular, neuroimaging studies reported activations evoked by dorsal penile stimulation either to the mesial wall (e.g., Allison et al., 1996; Makela et al., 2003; Nakagawa et al., 1998; see also Kell, von Kriegstein, Rosler, Kleinschmidt, & Laufs, 2005) or to the lateral surface of the postcentral gyrus (Bradley et al., 1998; see also Georgiadis & Holstege, 2005; Michels et al., 2010). During penile tactile stimulation, the secondary somatosensory cortex and the insula are also activated (see Georgiadis & Holstege, 2005, for a review).

In terms of the organization of the sensory homunculus, as proposed by Penfield and Boldrey (1937; see Chapter 2), the genitals seem to be discontinuous with the rest of the body, being represented below the toes (see Figure 13.1). Most of the available evidence supports a distinct dorsolateral location on S1 for both penis and clitoris, regardless of the nature of that stimulation (i.e., occurring in an intentionally erotic context or not; e.g., Georgiadis et al., 2006, 2010; Kell et al. 2005; Michels, Mehnert, Boy, Schurch, & Kollias, 2010). However, other studies have not confirmed the representation of the genitals within S1 as proposed by Penfield and Boldrey (1937). For example, using fMRI, Kell et al. (2005) showed a mediolateral sequence of somatosensory foot, penis, and lower abdominal wall representation in the contralateral S1 and a bilateral S2 representation in the parietal operculum.

A handful of studies have attempted to address the differences that exist between the cortical representation of male and female bodies, comprising genitals and erogenous areas. Note, for example, that in his pioneering study on cortical body representations in patients, Penfield reported very little about females (see Penfield & Rasmussen, 1950). In fact, the typical and now famous illustration of the map in S1 resulting from his studies is clearly male with testicles and penis, but no breasts, vagina, clitoris, uterus, or ovaries (see Di Noto, Newman, Wall, & Einstein, 2013, for a discussion of this point). Given that the anatomical locations of the genitals differs between males and females (e.g., consider that, with respect to the penis, most of the clitoris is internal; e.g., O'Connell et al., 2005), one might expect important difference in their cortical representation. In fact, neuroimaging studies have shown that the viscera activate brain regions distinct from those activated by external body parts (e.g., Kern, Jaradeh, Arndorfer, Jesmanowicz, Hyde, & Shaker, 2001).

Georgiadis, Reinders, Paans, Renken, and Kortekaas (2009) directly investigated the difference between male and tactile stimulation by means of brain imaging. They reported significant differences between male and female cerebral blood flow levels during tactile genital stimulation. More precisely, during the sexual tactile stimulation of the genitals, the right posterior claustrum, the insula, the secondary somatosensory cortex, and the right ventral occipito-temporal region were more active in men than in women. By contrast, the same stimulation led to a greater activation of the motor cortices, somatosensory area 2, and posterior parietal cortex in females than in males (Georgiadis & Holstege, 2005; Georgiadis et al., 2009). Georgiadis and colleagues also reported that these differences become less pronounced when the stimulation led to orgasm, when activations in the anterior lobe of the cerebellar vermis and deep cerebellar nuclei, and deactivations in the left ventromedial and orbitofrontal cortex were found in both men and women.

Interestingly, the stimulation of the genitals not only results in the activation of those brain areas where these body parts are represented. In fact, an fMRI study by Komisaruk and colleagues (2011) has demonstrated that a woman's self-stimulation of her nipples activates the medial paracentral lobule, in the region that is activated by genital self-stimulation. That is, the tactile stimulation of a non-genital erogenous zone can result in the activation of those brain areas that are involved into the representation of tactile information presented on the genitals. This result suggests that tactile sexual stimulation might be supported by a more

complex neural organization and be served by different subcircuits as compared to neutral tactile stimulation.

13.5.1 Pleasure centers

Evidence for pleasure centers in the brain also comes from those animal studies in which electrodes have been implanted into the brain and the animals can self-stimulate these structures by pressing a button. Electrodes capable of stimulating the brain are vigorously self-stimulated by rats in areas such as lateral hypothalamus, septum, accumbens, or the medial forebrain bundle (Olds & Milner, 1954; Shizgal et al., 2001; see also Berridge & Kringelbach, 2008). The stimulation often simultaneously motivates the animals to eat, drink, engage in sex, etc. (e.g., Hoebel, 1988; Valenstein et al., 1970). Similarly, a female human patient implanted with an electrode placed in the nucleus ventralis posterolateralis of the thalamus was reported to compulsively stimulate her electrode at home (Portenoy, Jarden, Sidtis, Lipton, Foley, & Rottenberg, 1986, p. 279): “At its most frequent, the patient self-stimulated throughout the day, neglecting personal hygiene and family commitments.” Following the stimulation of the electrode, the patient also reported a strong desire to drink liquids and some erotic feelings, as well as a continuing desire to stimulate again. Although the observations reported above might well be taken to suggest the presence of certain brain areas that are important for the generation of pleasant experiences, it is still unclear whether the stimulation of these brain areas actually causes sensations of “wanting” rather than truly of “liking” (see Berridge & Kringelbach, 2008, for a discussion of this point). The evidence emerging from the studies that have addressed this topic clearly suggest that there is not a specific “pleasure center” within the human brain. By contrast, a distributed network of areas including subcortical (such as the nucleus accumbens and ventral pallidum) and cortical regions (including the orbitofrontal cortex and anterior cingulate cortex) is responsible for our perception of pleasure (just as seems to be the case for our perception of pain; e.g., Melzack & Wall, 1965). It is also of importance to note here that a number of neuroimaging studies have shown that this brain network is involved in many different forms of pleasure, not necessarily related to sexual behavior (such as social pleasures or food; see Georgiadis & Kringelbach, 2012; Kringelbach, Stein & Van Hartevelt, 2012).

13.6 Conclusions

Tactile information processing is certainly relevant to our sexual behaviors. A number of studies have demonstrated that its importance might be related to the ability of the tactile sense to stimulate hormone release (e.g., Lindgren et al., 2010). Similarly, the presence of neural fibers that directly convey information regarding pleasant touch is another important aspect that differentiates the tactile sense from other sensory modalities and makes it unique when it comes to intimate relationships. The study of the possible role of CT fibers in sexual behavior is likely to flourish in the coming years and to bring fresh evidence to support the view that a dedicated tactile subsystem mediates our sense of well-being as well as our bodily pleasure.

The literature discussed in this chapter has also highlighted that a number of factors, including culture and subjective differences, likely contribute to affect our sexual responses to tactile stimulation. Future research should certainly concentrate on studying the complex interactions between physiological, perceptual, and cultural factors in our intimate tactile interactions. We believe that it is only through a multidisciplinary study of these areas that we will be able to offer the basis for the development of mediated forms of sexual behavior, such as in VR simulations or

distant relationships. Similarly, advances in our knowledge concerning the interactions between different aspects of tactile processing and, in particular, the interaction between touch and the other senses, will be able to provide new guidelines for the development of genital prostheses in the future.

In Chapter 14 we will deal with the important if often neglected role of touch on another of life's more pleasurable behaviors, namely eating and drinking.

Touch at the restaurant: A touch of gastronomy

14.1 Introduction

With his tactile dinner parties, the famous Italian Futurist F. T. Marinetti (see Figure 14.1) was perhaps the first to think creatively about the importance of touch and tactile stimulation to the act of eating, not to mention its enjoyment. His suggestion, in the *Manifesto della Cucina Futurista* was that in order to maximally stimulate the senses during eating, people should try wearing pajamas made of (or covered by) differently textured materials, such as cork, sponge, sandpaper, and/or felt (see also Adam & Galinsky, 2012, for evidence showing just how powerful the experience of wearing a certain item of clothing can be for the wearer; see also Chapter 15). He went on to recommend that diners should eat without the aid of knives and forks—by simply burying their faces in their plates to enhance the tactile sensations (see David, 1987, p. 61; Harrison, 2001, pp. 1–2)! The movement that Marinetti founded back in 1909 with the publication of *The Futurist Manifesto* in a Milan newspaper was, in many ways, way ahead of its time. The technology and knowledge needed to turn the Futurists' wondrous sensory aspirations into reality were often simply not available (see Apollonio, 1973, for a collection of many of these manifestos). That said, the last few years has seen something of a revolution in terms of our growing understanding of the role of touch in the experience of eating and drinking, and its exploitation in both everyday eating and drinking, as well as in context of experiential dining.

In this chapter, we will take a closer look at the various ways in which touch can influence the experience of eating, and how the latest scientific insights are now starting to make their way into an increasing number of our everyday dining experiences. The focus of the first part of the chapter will be on touch as it influences the experience of a diner in a restaurant setting. Later, we will look a little more closely at the oral-somatosensory contributions to the experience of the taste/flavor of foods and beverages. These in-mouth tactile sensations affect our food and beverage experiences no matter what we happen to be eating or drinking. Furthermore, they affect us no matter whether we realize it or not, and typically we do not. As we will see later in the chapter though, Marinetti would most likely have been happy with the developments that are now, finally, being realized, albeit a little over a century after he first founded the Futurist movement. The knowledge summarized in this chapter will hopefully be useful for the emerging field of experimental dining not to mention everyday food design.

As Brillat-Savarin (1835; see Figure 14.2), the famous French gastronôme knew only too well, the pleasures associated with eating and drinking constitute some of life's most enjoyable experiences. This, he thought, was especially likely to be true for the growing aging population (even more of a problem now than then). As he so eloquently put it in his still oft-cited early classic *The physiology of taste* (Brillat-Savarin, 1835, p. 14): “The pleasures of the table, belong to all times and all ages, to every country and to every day; they go hand in hand with all our other pleasures, outlast them, and remain to console us for their loss.” To the extent that this aphorism holds water,

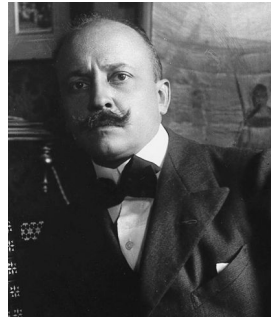


Fig. 14.1 The Italian Futurist, Filippo Tommaso Marinetti (1876–1944), author of *Il manifesto del tattilismo* (1921b) and *The futurist cookbook* (1930/1989).



Fig. 14.2 The famous French polymath, Jean Anthelme Brillat-Savarin (1755–1826). During his career, Brillat-Savarin worked as a musician, a lawyer, a politician, but is now perhaps best-remembered as the author of *The physiology of taste* (1835). Portrait of Jean Anthelme Brillat-Savarin (1755–1826) engraved by Lambert, May 1789 (engraving).

and given the (as we will see later) importance of touch and oral-somatosensation to the experience of tasting and flavor perception, even if few of us realize it, then one thing remains especially surprising: namely, that none of the many other books that have been published over the years on the topic of tactile perception (e.g., Field, 2001; Gordon, 1978; Hertenstein & Weiss, 2011; Katz, 1925/1989; Kenshalo, 1968) has ever mentioned the significant role that this sense plays in our experience of food and drink (just try eating a liquidized steak and think about the difference in your experience if you remain unconvinced).¹

¹ Remember what we saw in Chapter 2. The three bodily locations with the highest sensitivity to touch, presumably because of their importance to our evolutionary survival, are the fingertips, the tongue, and the lips (e.g., Penfield & Rasmussen, 1950 Weinstein, 1968). While many tactile psychophysicists have been more than happy to spend a lifetime studying the response characteristics of the human fingertips to tactile stimulation, far less research has been devoted to the study of the oral-somatosensory system. One might think of this neglect as akin to someone wanting to study human vision without bothering to investigate the workings of the fovea.

14.2 On the feel of a restaurant

In this chapter, we will review the evidence showing that the information we receive by means of the sense of touch (not to mention the related haptic, proprioceptive, and kinesthetic cues) play a subtle but nonetheless important role in many aspects of our eating and dining experiences (see Brillat-Savarin, 1835; Lieberman, 2011; see chapter 17 in Shepherd's, 2012, book). So, for example, think only about the chair on which you sit while dining at a restaurant. Taking inspiration from Marinetti, there would certainly appear to be grounds for thinking that simply by enhancing the tactile stimulation delivered by that point of contact with the restaurant, one might actually be able to enhance (or at the very least alter) the diner's experience.² A number of top-end restaurants have already started to put such ideas into practice. For example, Barb Stuckey (2012, pp. 85–86), in her book, *Taste what you're missing* describes a restaurant, "Saison," in her home state of California, where the chef/owner Joshua Skenes deliberately tries to stimulate the diners' sense of touch by placing a throw (with interesting tactile properties) over the back of each of the chairs.³ However, before too many other restaurateurs decide to follow suite investing in touchy-feely chairs, it is worth remembering that, as we saw in an earlier chapter, such unchanging background tactile information associated with the feel of the chair (or even the clothes on our body) isn't normally something that we pay all that much attention to. Rather, it provides a kind of constant tactile noise that typically fades very much into the background of our awareness (see Graziano et al., 2002; see also Ackerman et al., 2010). Note, however, that most of our experiences are made more or less enjoyable exactly by means of this background information (i.e., try to watch a movie sitting on your sofa or on an a chair in a crowded airport to see the difference!).

Presumably the pleasant feelings associated with dining off a table covered with a starched table-cloth (as compared to a plastic table-top, say) might serve much the same purpose (of stimulating the diner's sense of touch). Though, of course, in the former case, or even when thinking about the role that linen napkins might play in influencing the dining experience, it becomes much harder to separate any positive effects associated with the sensory properties (e.g., the sight or feel) of the material of the tablecloth (or napkins) from any cultural associations that we may have with such table coverings and fine dining experiences more generally (see Anderson, 2004; cf. Piqueras-Fiszman & Spence, 2011).

When considering the feel of a restaurant or bar, one might even think about changing the ambient temperature to create a certain impression on the diner. Relevant here, then, is the suggestion that more expensive stores (at least in New York) apparently have their air-conditioning set at a lower temperature than their cheaper competitors in the marketplace (see Howes, 2005, p. 288). At this point, think only of the Ice Bar concept (e.g., <<http://www.regent-streetonline.com/Eat-Drink-Relax/Ice-Bar-London.aspx>> downloaded on September 27, 2012) as an example of an extreme drinking environment where the temperature is congruent

² Furthermore, it is obviously going to prove much easier to get a diner to sit in a restaurant chair that happens to be covered in a stimulating "tactile" material than it would be to convince them to change into a pair of Marinetti's textured pajamas, say!

³ As Skenes describes it, when considering the remodeling of his restaurant: "You need great food, great service, great wine, great comfort. And comfort means everything. It means the materials you touch, the plates, the whole idea that the silverware was the right weight. We put throws on the back of the chairs" (Stuckey, 2012, pp. 85–86).

with the theme and creates thermal differentiation from the opposition; one in which the ambient temperature is dramatically different from what most of us are used to. The Ice Bar London, for example, keeps the temperature at a distinctly chilly -5°C . That said, drinkers are unlikely to be adversely affected by the cold given that everyone is provided with designer thermals to keep them warm before they enter. While there may be some interesting avenues to explore here when it comes to matching the atmosphere to the dish,⁴ such an approach should probably be treated with some degree of caution given the individual differences in ambient temperature that different people seem to find comfortable/acceptable (with women typically preferring a slightly higher temperature than men; Grivel & Candas, 1991; Landau, 2011; see also Kang et al., 2011).⁵

14.2.1 On the weight of the (wine) menu

In Chapter 11, we briefly mentioned an intriguing series of experiments in which Ackerman et al. (2010) demonstrated that people's judgments of other people (specifically, the qualities/characteristics of job candidates whose CVs they happened to be assessing) or our decisions about making an offer to buy an object (a car) can be influenced by something as seemingly irrelevant as the weight of a clipboard on which the CVs happen to be placed, or the hardness of the chair on which people were sitting. Reading about such results could certainly make one wonder whether the weight of the menu (e.g., in the setting of the restaurant) might not also influence a diner's (or for that matter, drinker's) choice behavior, not to mention their overall impression of the feel of a restaurant or bar. Might there be, for example, a correlation between the weight of the menu in a restaurant and the likely price of the food/wine that they happen to offer? And, if there is, have we consumers internalized that correlation (see Spence, 2011e)? One concrete question to address here in future research would therefore be to see whether it is possible to increase the average spend in a restaurant simply by increasing the weight of the menu. Of course, becoming aware of such manipulations might also help people to spend less! More generally, researchers working on this topic should try to understand how to match the weight of a menu with the overall experience that the restaurant's owner would like to communicate to his or her customer.

14.2.2 On the weight of the glassware

Do you think that a drink (e.g., a glass of wine or spirits, say) would taste better from a heavier cup/glass than from a light one? Our guess is that, in many cases, it would. However, this claim is not always going to be true. Drinking scotch from a cut-glass tumbler may well serve to

⁴ Certainly, changing the ambient temperature can provide an effective means of changing the atmosphere (and feel) of a theatrical production. This technique has been used very effectively by the Punchdrunk Theatre Company in their 2012 New York staging on Macbeth "Sleep no more" in an abandoned warehouse block (see Rose, 2012). One of the seven or eight floors on which the production was staged was set at a temperature that was noticeably lower than that of the others—entirely appropriate for an outdoor winter's night scene. But note here that the audience were free to move to a different floor should they find the temperature unpleasantly cold. Of course, such an opportunity isn't necessarily available to the diner seated in a restaurant.

⁵ Typically, people report feeling most comfortable at ambient temperatures of between $20\text{--}25^{\circ}\text{C}$ (see Grivel & Candas, 1991).

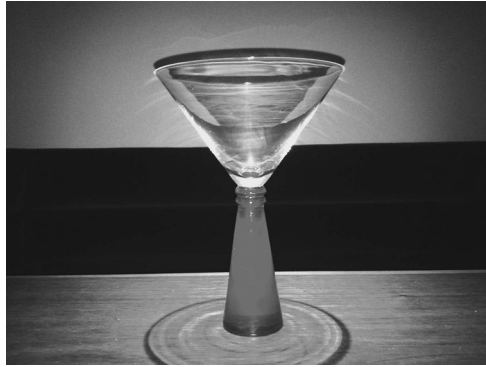


Fig. 14.3 A particularly heavy-bottomed Riedel beer glass. Photo—The Quilon restaurant.

improve the experience (due, in part, to the heavier weight of leaded glass as compared to other forms of glassware). By contrast, the quality of bone china tea cups is judged primarily in terms of the translucency of the porcelain (and hence presumably in this case lighter equals better).⁶ Meanwhile, wine sometimes seems to taste better from a heavy glass. On other occasions, though, the top (or, at least the most expensive) glassware (such as the very popular Riedel range of wine glasses can actually be surprisingly light) purportedly delivers the best taste (though see Spence, 2011e, for a review of the physical vs. psychological effects of a wine glass on our perception of the contents).

The Riedel beer glass shown in Figure 14.3 cleverly conveys the notion of weight to a drinker. Notice how, whenever the drinker tilts the glass to their lips, they have to rotate the weight of solid bottom half of the glass, thus perhaps once again conveying a satisfying notion of weight (and hence quality?) to the drinker (see Spence & Piqueras-Fizman, 2011).

14.2.3 On the weight of the wine bottle

A number of people (both wine writers and wine consumers) have commented in recent years on the increasing weight of certain wine bottles—think of those wines that come under the header of Super-Tuscans, for example (e.g., Goldstein & Herschkowitsch, 2010). We would argue that such manipulation in the marketplace (and yes we believe that the use of increasingly heavy wine bottles serves no other obvious purpose than to encouraging, possibly implicitly, shoppers to think the wine in their hand is of better quality) is designed primarily to convince the undecided shopper about which bottle represents better value for money (or quality). Nevertheless, the weight of the wine bottle will still likely have an effect in the majority of restaurants where

⁶ The favorite container of one of your authors for his 6 o'clock gin and tonic is a particularly heavy Hoeggarden glass. Inappropriate in one sense, it is, after all, a beer glass, and yet it is the most satisfying weighty of the glasses in the drinks cabinet. Perhaps, in part, in order to achieve a similar effect, mixologists sometimes take a large albeit light balloon wine glass and fill it with ice cubes prior to pouring in the gin and tonic. One can certainly think of this as another way of conveying the pleasant associations of weight to the contents (perhaps as a form of “sensation transference”; see Chapter 9).



Fig. 14.4 A particularly heavy bottle of wine. In this case, the sommelier explicitly commented to the diners present about the significance (in terms of the wine's quality, of the bottle's weight). As he put it: "You can tell that it's really good wine . . . Just feel the bottle . . . 1.5 kg empty!" Note that many other bottles weigh less even when full. Picture courtesy of Simon Spence.

the waiter doesn't pour the wine for you. (Although in this case, of course, the weight of the wine bottle is only experienced after the decision to purchase has been made, perhaps reassuring the costumer that his or her money was well spent!) Perhaps you too have had the experience of being in a restaurant and the waiter pointing to the quality of the wine indicated by highlighting the weight of the bottle to you (Cateno Zapata, from Argentina, for example, sell some extremely heavy bottles; see Figure 14.4). Or, as Goldstein and Herschkowitsch (2010, p. 80) put it when describing Bogle's wine bottles: "These Bogle bottles are hefty, and their weight is a nice feature – one that often tricks people into thinking the wine is more expensive than it really is." Research from Faraday Packaging Partnership and Glass Technology Services (2006) suggests that people's preference for drinks served from heavier bottles extends well beyond the world of wine bottles: they observed that consumers also preferred vodka when it was served from a heavier bottle.

Certainly, there is a significant correlation between the weight of the bottle and the price that you are likely to pay. When Piqueras-Fiszman and Spence (2012a) measured the weight of every single wine bottle in a wine store in Oxford (UK), they found that for every UK pound more on the ticketed price, the weight of the wine bottle increases by an average of 8 g (see Figure 14.5). The lightest bottles weighed in at 340 g, as compared to 1180 g for the heaviest bottle (both empty)—that is, the heaviest bottle weighed more than three times as much as the lightest bottle, all for the same 750 ml of wine.⁷

⁷ Wine bottles are a particularly interesting area to study in this regard since the majority of them contain the same amount (and hence weight) of wine. It may, of course, turn out to be for this very reason, that the manipulation of the weight of the packaging is more salient in this sector of the marketplace than elsewhere.

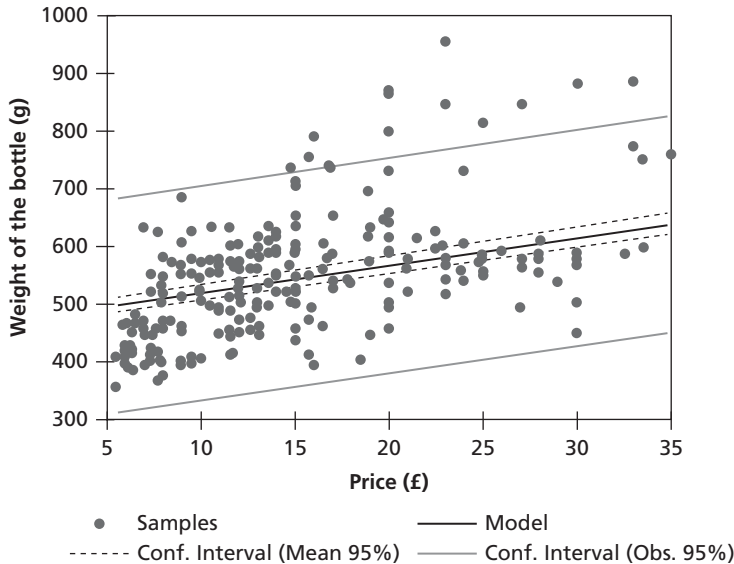


Fig. 14.5 Wine bottle weight—price correlation as reported in Piqueras-Fiszman and Spence (2012a, figure 1). Each point represents a bottle of wine. Reprinted from *Food Quality and Preference*, **25** (1), Betina Piqueras-Fiszman and Charles Spence, The weight of the bottle as a possible extrinsic cue with which to estimate the price (and quality) of the wine? Observed correlations, pp. 41–45, figure 1, Copyright (2013), with permission from Elsevier.

14.3 On the feel of the plateware

As the “Fur-Covered Cup” (1936) by Meret Oppenheim in Figure 14.6 so beautifully illustrates, the feel (either real or imagined) of plateware against our skin (especially against sensitive regions of the body, such as the lips) can generate unpleasant sensations. In fact, over the last couple of years, researchers have been investigating just what effect varying the weight and texture of the plateware has on people’s perception of the food served from it. While the visual pun of



Fig. 14.6 Meret Oppenheim’s (1913–1985) *Fur Covered Cup* (1936). Most people find the idea of putting their lips to such a textured cup rather off-putting. Just one extreme example, then, of how the texture of the plateware may affect us. Oppenheim, Meret (1913–1985): Object (*Le déjeuner en fourrure*), 1936. New York, Museum of Modern Art (MoMA). Fur-covered cup, saucer and spoon; cup 4 3/8' (10.9cm) diameter; saucer, 9 3/8' (23.7 cm) diameter; spoon, 8' (20.2 cm) long; overall height 2 7/8' (7.3 cm). Purchase. Acc. n.: 130.1946.a-c (c) 2013. Digital image, The Museum of Modern Art, New York/Scala, Florence. © DACS 2013.

Oppenheim's work was very much about something that people would likely not want to put their lips to, psychologists, together with modernist chefs and a growing number of food and beverage producers, are currently trying to make plateware/packaging that, by more effectively stimulating the sense of touch, manages to enhance the diner's (or consumer's) experience of food and drink.

Piqueras-Fiszman et al. (2011) published what is perhaps the first study to demonstrate that eating off of heavier plateware, at least when that plateware is held by the person doing the eating, also impacts on the perceived quality of the food (in particular, on both their sensory and hedonic evaluations). Piqueras-Fiszman and her colleagues had participants rate a spoonful of plain yoghurt served from visually identical bowls that varied only in terms of their weight (375 g, 675 g, and 975 g, respectively). The participants in this particular study sequentially held each one of the three bowls in one hand (with the order of presentation of the bowls counterbalanced across participants) while taking a spoonful of the plain yoghurt from each bowl with their other hand. The participants rated each of the yoghurts using a series of pencil and paper labeled line scales. The results revealed that the participants liked the yoghurt served from the heavier bowl significantly more than when exactly the same yoghurt was served from either of the other two lighter bowls. The participants in this study also rated the yoghurt contained in the heavier bowl as being significantly more expensive and significantly more dense (see Figure 14.7).

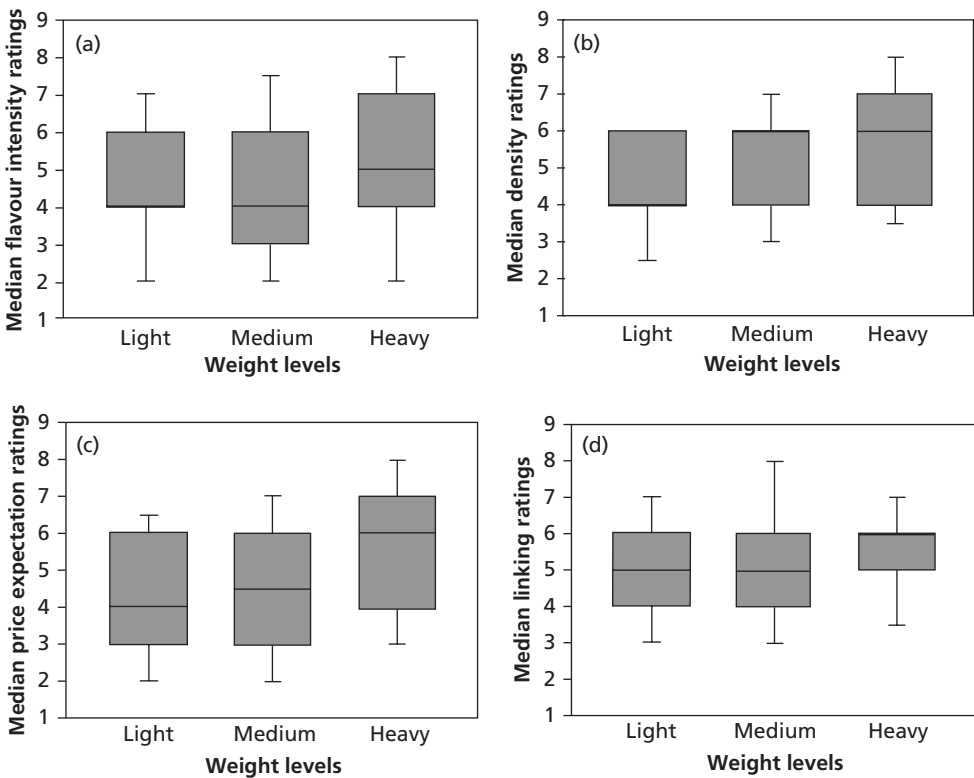


Fig. 14.7 Results of Piqueras-Fiszman et al.'s (2011) study showing how the weight of the plateware, at least when that plateware (a bowl in this study), is held in a person's hands, can enhance their perception of yoghurt. Median ratings (on a 9-point likert scale) of the yoghurt samples as a function of the weight of the bowls for (A) Flavor intensity, (B) Density, (C) Price expectation, and (D) Liking. Reprinted from *Food Quality and Preference*, **20** (8), Betina Piqueras-Fiszman, Vanessa Harrar, Jorge Alcaide, and Charles Spence, Does the weight of the dish influence our perception of food?, pp. 753–56, figure 1, Copyright (2011), with permission from Elsevier.

In their subsequent research, Piqueras-Fiszman and Spence (2012c) went on to demonstrate similar effects on people's ratings of yoghurt when served from either light (20 g) or heavy (95 g) plastic bowls (see also Spence & Piqueras-Fiszman, 2011). This time, note, the absolute variation in the weight of the plateware was much subtler, and yet the yoghurt tasted from the heavier pot was still estimated as likely to be more satiating (prior to consumption), denser (once again), and as likely to be more filling, after it had been tasted (see Brunstrom et al., 2010; Brunstrom & Wilkinson, 2007).⁸

There are, however, many other everyday examples of where changing the plateware/manner of eating appears to enhance the experience of the food. For those who are old enough (and British), you may remember the experience of eating fish and chips from a newspaper wrapping, or seafood from the shell (in this case also for those from the Mediterranean). Somehow the very same food never seemed to taste as good when eaten off of a plate while sitting at the table. Or, for those who are a bit younger, just contrast the experience of eating a hamburger with one's hands, versus with a knife and fork. Our feeling is that most people much prefer the former situation. Given that increasing the weight of the plate appears to enhance a diner's experience of a dish (at least when that dish is held in the hand, and at least for the first bite/taste of a dish),⁹ as a restaurateur, one might be wondering already how to get one's customers not simply to eat with the plate resting on the table (as is normally the case). To this end, in the Crossmodal Research Laboratory in Oxford, we are currently working with a ceramicist in order to create a range of bowls that will have rounded bottoms. These bowls would ideally spill their (liquid) contents should they be placed directly onto the dining table when presented to the diner. While the spontaneous response of the diner to such a design might be "What a silly idea!" it might actually be an effective design if what you are trying to do is to ensure that the diner experiences the satisfying weight of the dish for themselves.

Now it turns out that it is not only the weight of the plateware that matters, but also its texture (especially when held in the hand, and hence felt by the diner). Suggestive evidence in this regard comes from Piqueras-Fiszman and Spence (2012d). They recently demonstrated that people rated pieces of digestive biscuit (either stale or fresh) served from a small plastic yoghurt pot as both crunchier and harder when the container had been coated with a rough sandpaper finish, as compared to when exactly the same food was served from a container with the usual smooth plastic feel of a yoghurt pot (see Figure 14.8).¹⁰ Anecdotally, we have also heard that people holding a handful of gravel in one hand will rate ice cream as tasting grittier if than if they grasp a handful of cotton wool instead. Note that in this case, given that the majority of people do not generally tend to keep the plate in their hand while eating, one might find alternative strategies to force the costumer to touch the plate (i.e., by placing the food in a position of the plate that requires the eater to turn it in order to eat).

⁸ Of course, such results obviously raise some concerns for companies when it comes to thinking about the consequences on product perception of recent moves toward light-weighting (e.g., see Stones, 2010; Spence & Piqueras-Fiszman, 2012).

⁹ Note that this is one potential criticism of many of Piqueras-Fiszman and colleagues' studies on weight. Namely, their participants only ever assessed their first bite (or taste) of a particular food. Note here that there are examples from the food science literature where, for example, preferences, and judgments, change, or even, on occasion, reverse, when an entire plateful or glassful of food has been polished off (as compared to their judgments based on the first mouthful, or sip).

¹⁰ It should, however, be noted here that while the feel of the container influences participants' perception of a dry food product, it had no such effect on their ratings of yoghurt. Further research will therefore be needed to understand the limiting conditions on this particular crossmodal effect.

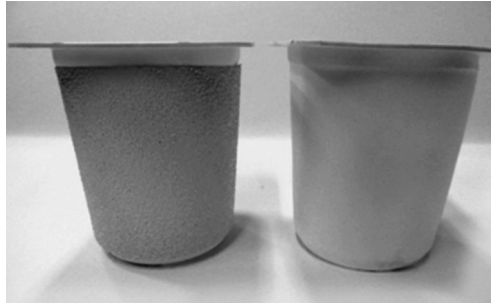


Fig. 14.8 The rough and smooth food containers used in Piqueras-Fizman and Spence's (2012d) recent study of texture transfer effects. Pieces of biscuit (stale and fresh) were rated as tasting significantly crunchier and harder when sampled from the rougher container shown on the left, than when tasted from the smoother container shown on the right. Interestingly, however, participants' freshness and liking ratings were not affected by the variation in the pot's surface texture, but only by the texture of the food itself. That is, the fresh food samples were, unsurprisingly, perceived as being fresher and more liked than the stale biscuits, regardless of the container in which they were presented. Reprinted from *Food Quality and Preference*, **20** (8), Betina Piqueras-Fizman, Vanessa Harrar, Jorge Alcaide, and Charles Spence, Does the weight of the dish influence our perception of food?, pp. 753–56, figure 1, Copyright (2011), with permission from Elsevier.

Thus, to summarize the findings reported in this section, the weight (Piqueras-Fizman et al., 2011; Piqueras-Fizman & Spence, 2012a; Spence & Piqueras-Fizman, 2011), the texture (Piqueras-Fizman & Spence, 2012d), and possibly even the temperature (see Williams & Bargh, 2008, discussed later) of the plateware and glassware can all be modified in order to enhance (or, at the very least, to modulate) a diner's multisensory experience of food and drink. What is also worth noting here, though, is that not everyone is necessarily likely to be similarly affected by the feel of the tableware. For results originally reported by Peck and Childers (2003a, b), and followed-up more recently by a number of other researchers (e.g., Krishna & Morrin, 2008), suggest that there are stable and significant individual differences in terms of people's need for touch. As we saw in Chapter 11, some people who score higher on the "Need for touch" scale developed by Peck and Childers seem to prefer a greater degree of tactile contact than those who score lower. Particularly relevant in the context of the present chapter are findings collected by Krishna and Morrin. They reported that those who score higher on Peck and Childers's questionnaire tend to be influenced more by the feel of a flimsy water container than those who score lower on the scale.

14.4 On the weight and feel of the cutlery

Researchers have recently started to turn their attention to the area of cutlery design (e.g., Harrar & Spence, 2012; Howes et al., submitted; Piqueras-Fizman et al., 2012; Piqueras-Fizman & Spence, 2011; Spence & Piqueras-Fizman, 2011), and, as we will see later in this section, a number of insights from this research are already starting to appear in the context of experiential dining. In one study, for example, Piqueras-Fizman and Spence had their participants sample vanilla yoghurt using either a heavy or a light spoon (4.9 vs. 19.2 g, respectively). The participants in this study liked the yoghurt sampled with the aid of the heavier spoon more than when exactly the same food was tasted using the lighter spoon. Additionally, the yoghurt was rated as of significantly higher quality (when rated with the heavier spoon), even if the weight of the spoon did not affect the rated intensity of the vanilla flavor. Harrar and Spence (2012) reported similar results when they varied both the weight and size of the spoons independently.

Given the beneficial effects of adding weight (no matter whether that is adding weight to the wine bottle, to the plateware, or to the cutlery), the following anecdote should not come as such a surprise. A few years ago a design firm was commissioned with developing some ultra-lightweight yet stylish cutlery for use on Concorde (the recently decommissioned supersonic jet). The designers decided to use titanium as the material of choice. However, although beautifully made, the cutlery was so light that passengers simply did not like eating with it (Piqueras-Fiszman & Spence, 2011). It just didn't feel weighty enough! In this case, the negative response of passengers to the weight of the cutlery outweighed its aesthetic appeal, and the beautifully designed cutlery was never brought into service.

Elsewhere, researchers have been investigating how the material properties of the cutlery affect the taste of food. For example, Piqueras-Fiszman et al. (2012) recently demonstrated that eating with the aid of different spoons (coated with silver, gold, copper, stainless, steel, etc.) made food (in this case, cream samples to which salt, sugar, citric acid, or caffeine had been added) taste different. However, these results are unlikely to have had anything to do with touch per se, since the participants were blindfolded prior to being presented with each of the spoons, and hence it was the spoons' material properties that affected the taste. (Of course, this is not to say that had the participants kept their eyes open in this study, the different spoons might not have imparted an even larger impact on the taste of the creams.)

In terms of those practitioners who are currently using the insights of such laboratory-based research in a real dining context, one need to look no further than the conceptual culinary artist Caroline Hobkinson (see <<http://www.stirringwithknives.com/>> downloaded on October 27, 2012). Over the last couple of years, she has hosted a number of culinary events in which she has been experimenting by providing her diners with a variety of unusual eating utensils to work with. In one of her dishes, for example, the diners use carved deer antlers in order to "spear" the food from the table (see Figure 14.9).



Fig. 14.9 Diners enjoying traditional Scottish venison—but with a somewhat unusual choice of cutlery. © Glenfiddich Pioneers Summit, Initiation Dinner, Scotland 2011, curated by Caroline Hobkinson, photo courtesy of Glenfiddich.

On October 1, 2012, The House of Wolf opened in London's Islington (see <<http://houseofwolf.co.uk/>> downloaded on September 27, 2012). The inaugural chef (note that the chef rotates every month or so) Caroline Hobkinson, created a series of courses designed to sequentially stimulate each of the diner's senses (see Figure 14.10 for the menu highlighting those dishes designed to stimulate the sense of touch). One dish on the menu included the use of antlers as cutlery, while another of the dishes (again designed to more effectively stimulate the diner's sense of touch) was a "Hendrick's gin-infused cucumber Granita." This dish was eaten with spoons that had been treated with rose water crystals and Malden sea salt to give them a distinctive and unusual texture (see Figure 14.11).

It is interesting to note that a number of restaurants have started to appear (e.g., Il Giambellino in Milan in Italy; <<http://www.ilgiambellino.it/>> downloaded on September 27, 2012 is one of them) where no cutlery is provided. That is, people have to eat using only their hands (see Di Gregorio, 2012a, b and think only of the pleasure of sticking one's finger in the cake mix bowl and licking one's fingers. It just doesn't seem to taste the same if you use your fingers).¹¹ Finally, we

LOOK. LISTEN. SMELL. TOUCH. EAT!
 A fully immersive sensory dining experience by Caroline Hobkinson
 In collaboration with Experimental Psychologist Professor Charles Spence

AMUSE BOUCHE
 Insert your earplugs
 Devour the freshly baked Bread roll without the use of your hands
 Neuroscience has revealed a deep 'cross modal' connection, sounds can actually
 change how we perceive food experiences.
 Can you hear the taste?

SIGHT
 Blindfold yourself
 Your waiter will describe the dish to you
 A Cracker bread is placed in front of you
 The Smell of Roast Peppers and Fresh Rosemary is distributed
 Remove your blindfold
 Can you see the taste?

SMELL
 Salmon Sashimi accompanied by a Syringe filled with Ardbeg Ten Years Old.
 Revered as the peatiest and smokiest Single Malt.
 Inject the Salmon with the Whisky and eat it
 Reconstruct the taste of Smoked Salmon with the Smokey Scent
 Taste sensations are picked up chemically by our tongue.
 The sensation of flavour is a combination of taste and smell. Most of flavour is smell.
 Can you smell the taste?

TOUCH
 Palate cleanser
 HENDRICK'S Gin infused Cucumber Granita
 Slurp with texture treated spoons with
 Rose Water Crystals and Maldon Sea Salt

TOUCH
 Main
 Saddle of Venison with foraged Prunes, Chanterelles and Wild Cherries
 Grab the hand carved long tree branch and spear it
 Can you feel the taste?

SOUND
 In collaboration with Condiment Junkie
 Sonic cake pop
 Please take your phone
 Dial 0845 680 2419
 Research at Oxford University proved that by changing a sound alone we can change a
 taste from Bitter to Sweet.
 A low note brings out the Bitter, a high pitched sound brings out the Sweet flavour.
 Can you dial a taste?

Fig. 14.10 The opening menu from the House of Wolf restaurant, London. Menu created by Caroline Hobkinson. Note how different dishes are designed to stimulate each of the diner's senses.

¹¹ Note that some marketers have recently started to capitalize on such observations. One clear example of this comes from Kraft who used the slogan "Se non ti lecchi le dita godi solo a metà" [If you don't lick your fingers you only half enjoy it; where in Italian "godi" is also related to sexual enjoyment] to advertise in Italy their "Fonzies" crisps.

Fig. 14.11 The textured spoons presented to diners for one of the touch courses at House of Wolf, which opened in London's Islington in 2012 (see <<http://www.stirringwithknives.com/>> figure downloaded on September 27, 2012, with permission of the chef).



are aware of at least one Michelin-starred restaurant in Bilbao named Narua (<<http://www.nerua.com/>> downloaded on November 9, 2012) where the warm plates are served with warm cutlery, and the cold dishes are eaten with the aid of chilled cutlery. There when the service starts, the diners find an empty table: no cutlery, no glasses, no plates. Then the waiter/waitress brings to the customer a warm napkin, with the aim of transmitting tenderness and care. Finally, the cutlery is served, and depending on their temperature the diners can know if the plate which is going to be served next will be warm or cold.

14.5 Mouthfeel and the oral-somatosensory aspects of food and drink

It turns out that oral-somatosensation plays a crucial role in many aspects of our multisensory perception of flavor even if research has very little considered this topic. In fact, most of the extent literature on oral haptic perception has only investigated aspects related to oral haptic object localization (Anstis & Tassinari, 1983; Benedetti, 1988b), or perceived tongue position (Grover & Craske, 1992). While many people believe that flavor is all about the taste we perceive via the tongue, it turns out that all of the senses are involved (see Stevenson & Mahmut, 2011). Olfactory cues are especially important in telling us about flavors (such as meaty, fruity, burnt, etc.) rather than just about basic tastes (sweet, sour, bitter, salty, and umami¹²). However, what we see, hear, and feel are also incredibly important to the overall multisensory

¹² uMami can be described as a pleasant savory taste found in foods such as meat, cheese, and mushrooms. It induces salivation and a sensation of furriness on the tongue, not to mention the roof and back of the mouth (see Yamaguchi, 1998). This taste appears to be due to the detection of the carboxylate anion of glutamate in specialized receptor cells on the tongue (e.g., Chandrashekar, Hoon, Ryba, & Zuker, 2006).

flavor experience (see Spence, 2012b, c). The tactile stimulation we receive in-mouth informs us about everything from the temperature of the food through to its texture (e.g., Szczesniak, 1990; Szczesniak & Kahn, 1971, 1984; Szczesniak & Kleyn, 1963; see Green 2002; Green & Lawless, 1991; Stevenson, 2009, for reviews). Bourne (1982, p. 259) defined food texture as: “the response of the tactile senses to physical stimuli that result from contact between some part of the body and the food.” More recently, other researchers have been tempted to include a contribution from the other senses, such as vision, hearing, olfaction, and kinesthesia in their definitions as well (e.g., Szczesniak, 1990). In terms of typical descriptions of oral texture, one might think of whether a foodstuff feels sticky, slippery, gritty, etc. in the mouth.

When it comes to the tactile experiences associated with the consumption of food and drink, they are obviously important, though typically fall behind taste and smell in people’s (e.g., those working in the food industry) ratings. According to the results of one survey of 140 people working in various capacities in the area of food/chemical senses by Jeannine Delwiche (2003), temperature and texture came out ahead of color, appearance, and sound in people’s rankings of the importance of various cues to flavor perception. While oral-somatosensory cues do not fall under official definitions of flavor,¹³ they are nevertheless increasingly coming to be recognized for the integral role they play in our experience of food and drink.

That said, it is actually not always so easy to ascertain exactly which sense is actually doing the work in terms of giving rise to specific aspects of our multisensory experience of food and drink (see Spence, Smith, & Auvray, in press). For example, just take attributes such as carbonation, fattiness, and astringency. While the intuitive view might be that the experience of carbonation in the mouth is attributable to the *feel* of the bubbles bursting on the tongue, it turns out that carbonation is as much a result of the stimulation of the sour *taste* receptors on the tongue (e.g., Chandrashekar et al., 2009). Meanwhile, most would intuitively say that the perception of fat in a food is an oral-somatosensory textural attribute. However, it turns out, though, that much of our experience of the fattiness of food comes not just from the oral-somatosensory texture/consistency of a foodstuff in the mouth. As we will see, olfactory and gustatory cues are also very important to the perception of fattiness in a food (Bult et al., 2007). Indeed, a number of researchers now argue that one of our basic tastes, i.e., along with sweet, sour, salty, bitter and umami, may be the taste of certain fatty acids (e.g., Mattes, 2009). Astringency too, as in an overstewed cup of tea or in a tannic young red wine that has been fermenting in new oak barrels is actually a tactile sensation, though many think of it as part of the taste/flavor of a beverage (Breslin et al., 1993).

The oral-somatosensory attributes of food also give rise to what food science researchers often refer to as the “*mouthfeel*” (e.g., Christensen, 1984; Gawel et al., 2000; Kappes et al., 2007; Langstaff et al., 1991; Marsilli, 1993; Szczesniak, 1979). This is the term used to describe the feeling that we have in our mouths on, and after, eating a certain food or drink. Olive oil, for example, may give rise to an oily mouth-coating, while foods containing menthol may well give rise to a cool mouthfeel. Jowitt (1974, p. 356) describes mouthfeel as “those textural attributes of a food or beverage responsible for producing characteristic tactile sensations on the surfaces of the oral cavity.” Typical mouthfeel characteristics include sticky, astringent, stinging, oily etc.: “Think of the creaminess of mayonnaise, the viscosity of toffee and the greasiness of cold lard. Or the brittleness

¹³ According to the International Standards Organization (see ISO 5492, 1992, 2008), flavour is defined as a: “Complex combination of the olfactory, gustatory and trigeminal sensations perceived during tasting. The flavour may be influenced by tactile, thermal, painful and/or kinaesthetic effects.”

of butterscotch, the elasticity of jelly and the crunchiness of fresh carrots. Careful not to dribble. You have entered the complex world of mouth feel” (“Mouth feel,” 2005, p. 47).

Mouthfeel is also an important aspect of our appreciation of many alcoholic beverages such as beer and wine (e.g., Gawel et al., 2000; Langstaff et al., 1991). Just take the following quote from Richard Gawel, developer of the Mouth-feel Wheel: “Just listen to red wine consumers when they explain why they like, or don’t like a particular red wine. Wines that they perceive as ‘soft’ and ‘smooth’ in the mouth are frequently at the top of their shopping lists. This convinced me of the merits of compiling an extensive list of defined terms that could be used by wine-tasters to describe red wine texture” (Gawel, 2006).

A recent study by Topolinski, Türk, and Pereira (2012) has recently investigated an interesting aspect of oral-somatosensation. They studied the effect of the subjectively reported status of the participants (hungry or satiated) on the oral and haptic manual perception of the size of objects (straw segments). They found that objects were perceived to be larger when the participant was hungry than when satiated and that this effect occurred for oral but not for haptic perception. The researchers also reported that the effect completely vanished after oral stimulation. The authors concluded that food deprivation involves tactile and haptic deprivation of the oral mucosa leading to increased sensitivity and thus overestimation of sensory qualities. That is, an important relationship exists between oral stimulation of the mucosa, our feelings of being hungry, and the perception of food characteristics (such as its size).

The oral texture (in particular, the viscosity) of food and drink turns out to exert a significant influence on our multisensory perception of flavor (e.g., Bult et al., 2007; Frost & Janhøj, 2007; Weel et al., 2002). While the results of a number of early studies in this area (e.g., Christensen, 1980) led to the suggestion that increased viscosity in a foodstuff impaired the perception of taste, it has, for many years, been difficult to disentangle whether such effects had a physicochemical, as opposed to a neurophysiological, origin (since increased viscosity is likely to reduce volatility at the food–air interface; see Delwiche, 2004). However, the technological advances that have been seen in the field of food science research over the last 10 years or so now mean that it is possible to isolate (and thus to demonstrate) the genuinely psychological nature (of at least a part) of this crossmodal effect (e.g., Bult et al., 2007; Kutter et al., 2011). How, some might ask, is this done?

In one study, Bult et al. (2007) presented participants with a creamy odor using a computer-controlled olfactometer (a technical name for a smell-delivery machine). The olfactory stimulus was either presented orthonasally or retronasally.¹⁴ At the same time, milk-like foods with different viscosities were delivered to the participant’s mouth. The participants had to rate the thickness and creaminess of the resulting experience as well as the intensity of the overall flavor experience. Crucially, the participants’ ratings of the intensity of the flavor decreased as the viscosity of the liquid increased, regardless of how the odor was presented (i.e., orthonasally or retronasally). Given the independent control of texture and odor delivery in this particular study, the results clearly highlight the important role that texture (mouthfeel) plays in multisensory flavor perception in

¹⁴ Nowadays, researchers believe that there are actually two relatively distinct senses of smell. The orthonasal system is associated with the inhalation of external odors while the retronasal system is associated with the detection of the olfactory stimuli emanating from the food we eat, as odors are periodically forced out of the nasal cavity when we chew or swallow a food (or drink). Indeed, a growing body of empirical research currently highlights a number of important differences between these two kinds of smell, both at the subjective/perceptual level (e.g., Diaz, 2004; Rozin, 1982), and in terms of the neural substrates that appear to be involved (e.g., Small et al., 2005, 2008).

humans. Finally, Bult et al.'s results also suggest that the presence of a retronasal odor can alter the perceived thickness of a foodstuff in the mouth (see also Sundqvist et al., 2006; Tournier et al., 2009).

The tactile stimulation of the oral cavity is also important for another reason too: everyone has heard of the ventriloquist—the illusionist who projects his/her voice to the articulated lips of the dummy (see also Chapter 11, for the concept of “affective ventriloquism”). This illusion provides a particularly well-known example of the visual capture (or, more commonly, bias) of perceived auditory location (Alais & Burr, 2004). A very similar effect may also be taking place in our mouths whenever we eat or drink. For it turns out that where we localize a taste follows the location of a tactile stimulus drawn across the tongue and not the point where the taste stimulus itself happens to be transduced on the receptor surface (Green, 2002; Lim & Green, 2008; Todrank & Bartoshuk, 1991; though see Stevenson, 2012). The same may also be true for olfactants—that is, they too are localized to the location of oral-somatosensory inputs (Murphy & Cain, 1980).¹⁵

The ventriloquism illusion may also play a crucial role in one of the classic dishes on the tasting menu at Heston Blumenthal's, The Fat Duck restaurant in Bray, UK. When bacon-and-egg flavored ice cream was first created, it was only moderately pleasant; that is, the flavors did not appear to stand apart from one another. Part of the breakthrough came when a piece of crispy fried bread was added to the plate. While the bread does not, in-and-of-itself, impart much of a flavor to the dish, its addition seemed to bring the dish alive by helping to separate the bacon and egg flavors. What may be going on here is that the bacon flavor is ventriloquized toward, and hence becomes perceptually localized within, the crispy bread (i.e. congruent with the texture of crispy bacon), while the egg flavor stays behind in the more texturally appropriate soft ice cream (see Blumenthal, 2008; Spence, 2010c).

Another kind of crossmodal interaction involving oral-somatosensation takes place between temperature and taste. Roughly a third to a half of the population experience what is known as the “*thermal-taste*” illusion (Cruz & Green, 2000; Green & George, 2004). This term refers to an effect that was first documented by Barry Green and his colleagues at Yale University a little over a decade ago. They found that simply by raising or lowering the temperature at various points on a person's tongue, they were able to elicit sensations of sweet, sour, salty and bitter—i.e., the four main basic tastes. (You can try this at home by taking an ice cube and placing it against different parts of your tongue. Some people will, for example, likely experience sweetness and/or saltiness when the cube is rubbed across the tip and front sides of the tongue.) Note that this taste experience is completely illusory given that the water in ice cubes normally has no taste.

Oral-somatosensory information regarding the food or liquid in the mouth is transferred to the brain by means of the trigeminal nerve, which projects directly to the primary somatic sensory cortex (Simon et al., 2006). This projection carries information concerning touch, texture (mouthfeel), temperature, and proprioception (not to mention nociception or oral pain, and chemical irritation) from the relevant receptors in the mouth. The results of various neuroimaging

¹⁵ Note, also, that given the pronounced differences in transduction latencies between the senses, the tactile sensations associated with eating and drinking will normally arrive centrally in the brain before either the associated gustatory or retronasal olfactory stimuli, and hence this “prior entry” of the tactile signal may also play some role in the combined multisensory flavor experience being localized to the mouth as well (see Spence, 2012a).

studies suggest that oral texture appears to be represented in the OFC amongst other areas (Cerf-Ducastel et al., 2001; Eldeghaidy et al., 2011). The texture of fatty foods also appears to light up the cingulate cortex (see De Araujo & Rolls, 2004). Note that, as seen in Chapter 13, these areas of the brain are ontogenetically older as compared to other brain areas and have been found to be related to the processing of pleasure and reward. In fact, recent studies have demonstrated that the brain networks supporting the food pleasure cycle are remarkably similar to those underlying the processing of other rewards such as those following from sexual behavior (Kringelbach et al., 2012; see also Crumppacker, 2006, on the relationship between food and sex). Evolutionarily speaking, it may have been important for our ancestors to have detected the textures of fatty foods, since that would normally have been a good sign that the food constituted a good source of energy.

It is worth noting how many of our food likes and dislikes are also dependent on the oral-somatosensory texture of particular foodstuffs (e.g., Prescott, 2012; see also Munoz & Civille, 1987). For example, for many Asian consumers, it is the texture of the rice pudding that they find so off-putting. By contrast, for the Westerner breakfasting in Japan, the fermented black natto has a texture and consistency that isn't quickly forgotten. As John Prescott (2012, pp. 25–26) points out in his book, *Taste matters*: “Other less obvious tactile sensations are also important in food acceptability. In particular, problems with texture are a common reason for rejecting foods.” Take, for example, the oyster, what the British food critic A. A. Gill memorably described as “Sea-snot on a half-shell” (*Sunday Times*, November 8, 2009; see Prescott, 2012, p. 26). It is this shellfish's slippery texture, and not its taste or flavor, that people typically find so objectionable. As Prescott continues: “The oyster is a pre-eminent example of the role that texture often plays as a reason for rejection of a food.”

That said, a food's textural properties can also constitute a key part of what we find so pleasing (addictive) about certain other foods. Indeed, a number of researchers have argued that is part of the appeal of chocolate, one of the few foods to melt exactly at mouth temperature (see Stuckey, 2012). (Just try eating very cold versus warm chocolate bar to experience the difference in their flavor for yourself.) Texture, then, plays a crucial role in determining our perception of a food's quality, its acceptability, and eventually our food and beverage preferences (e.g., Guinard & Mazzuchelli, 1996; Szczesniak, 2002). Texture contrast is obviously also something that many chefs work with (e.g., Stuckey, 2012, pp. 93–95), and that consumers are known to value in a food (Szczesniak & Kahn, 1984): “Good chefs go to great lengths to add texture contrast to their plates, utilizing four different approaches: within a meal, on the plate, within a complex food, and within a simple food” (Stuckey, 2012, p. 93).

Intriguing neuroimaging evidence has shown that an individual's taster status will influence their experience of the oral-somatosensory qualities of food (Eldeghaidy et al., 2011). The available evidence now suggests that those described as “supertasters” (Bartoshuk, 2000) are more sensitive to fat in foods such as ice cream and salad dressing (Tepper & Nurse, 1997; though see Yackinous & Guinard, 2001). Intriguingly, Wang et al. (2002) have even reported that those individuals who are obese appear to have increased resting activity in the oral-somatosensory cortex as compared to those individuals are not obese.

Experiments conducted at the Crossmodal Research Laboratory in Oxford over the last decade have demonstrated that food-eating sounds also contribute to our perception of crispness and freshness in foods such as crisps (potato chips), biscuits, breakfast cereals, and vegetables (Masuda et al., 2008; Spence, 2012b; Zampini & Spence, 2004). The participants in one study by Zampini and Spence (research for which the authors were awarded the 2008 IG Nobel prize for nutrition) had to bite into a large number of potato chips (around 180 in total) and rate each

one on its perceived crispness and freshness. The crisp-biting sounds were picked up by microphone, modified, and then immediately played back over headphones. Importantly, the crisps were rated as tasting significantly crisper (and fresher) if the overall sound level was increased, or if just the high frequency components of the crisp biting sound were boosted. Furthermore, subsequent research has shown that people's perception of the crispness of potato chips can also be modified, albeit more subtly, by changing the sound of the packaging that people hold (Spence et al., 2011). Elsewhere researchers have noted that the perception of carbonation in a beverage served in a cup can also be modulated by what a person hears (Zampini & Spence, 2005). Thus, such results demonstrate that much of our perception of the texture of foods in mouth actually depends on the sounds that we hear while eating and drinking (see Spence, 2012b, for a review; see also Gallace, Boschini, & Spence, 2011, for the associations between the sound of the food name and certain tactile qualities of the food). The latest research shows that even the sound that a drink makes when poured may provide useful information regarding the likely temperature of that drink (hot vs. cold) when grasped or brought to the lips (see Velasco, Jones, King, & Spence, *in press*).

14.6 On the social aspects of touch in the restaurant

Now, the social (or interpersonal; Bolanowski et al., 1999) aspects of touch are also important in the context of the restaurant or bar (e.g., “the Midas Touch,” which was described in detail in Chapter 7). In particular, it has previously been shown that both male and female participants in a study by Crusco and Wetzel (1984) tipped significantly more after having been touched than when they were not touched by a restaurant waiter/waitress. Subsequent research by Stephen and Zweigenhaft (1986) has now replicated this basic phenomenon. Meanwhile, elsewhere, researchers have demonstrated that drinkers tend to consume more food if touched by a waitress (Kaufman & Mahoney, 1999). To put a number on the effect of social touch, in one study those people drinking in pairs consumed about 30% more after having been touched by the waitress (see also Guéguen, Jacob, & Boulbry, 2007 for the report that a suggestion by the waiter/waitress of a restaurant about the meal had a more positive effect on the actual customer's choice when the customers were touched by the employee as compared to when they were not touched). Of course, it is worth mentioning here that this kind of manipulation/social interaction might be more acceptable to people in certain countries than others (Hall, 1966; Remland & Jones, 2005).

While we are on the topic of touch/tactile stimulation and tipping, waiters the world over might want to take note of Williams and Bargh's (2008) finding that people's judgments of other people tend to be more positive after having briefly held a cup of hot coffee than after having held a cup of iced coffee instead. Recommending a hot drink to end the meal might then also be expected to lead to increased tipping. Importantly, and this is often the case in this kind of study, those who took part in Williams and Bargh's study were completely unaware of the influence that the temperature of cup was having on their interpersonal judgments.

14.7 On the future of touch at the restaurant

One trend that is popular currently relates not to the enhancement of specific sensory cues but to their very removal. Surely you have already heard about (and may well have tried) one of the dine-in-the-dark restaurants that have been popping-up in many large cities over the last decade or two (see Spence & Piqueras-Fiszman, 2012, for a review). Now a number of restaurateurs/chefs offering experiential dining are currently starting to experiment with the removal of auditory cues as

well (e.g., by means of getting the diner to wear a pair of ear plugs; see Spence, 2012c). What then, one might ask, about removing the sense of touch/haptics? One example of this comes from a most memorable experience when dining at Heston Blumenthal's The Fat Duck restaurant in Bray nearly a decade ago. At that time, when a number of the dishes involved experiences that were perhaps a little more cutting-edge and risky than they are today, one, in particular, stands out (both at the time and in the author's recollection of a dinner eaten almost a decade ago now). For one of the courses on the tasting menu, the waitress would arrive at the table, and instruct the diner to "open wide" (or some such phrase) before inserting a spoonful of the latest molecular gastronomy creation (lime gelee in this case) into the diner's mouth. Note that by so doing, many of the tactile/haptic elements normally associated with eating, such as the holding and wielding of cutlery had been removed. (Marinetti would, one presumes, have approved.) However, while such an experience can be framed in terms of the removal of many of the tactile/haptic cues that one normally receives while eating, it can be argued that much of the emotional power of this dish comes from the invasion of personal space, and the way in which being literally spoon-fed takes one back to childhood (the lime gelee presumably helping to cement this association) when one was fed in this manner by one's care-giver (<http://www.andyhayler.com/show_restaurant.asp?id=226>, downloaded on September 28, 2012).

Another much more recent example of eating without the aid of cutlery comes from one of the meals organized by the conceptual artist/chef Caroline Hobkinson whose work we came across earlier. In one wonderful dish/experience, tasty morsels of food were tied to virtually invisible fishing wire and suspended from helium balloons that nestled under the ceiling. The diners/guests entered a dark room, one in which the food is only sparingly lit, and hence it appears to be floating in mid-air (see Figure 14.12, for a similar use of hanging food from one of Caroline Hobkinson's culinary installations). The diners were then encouraged to eat the food using nothing more than their mouths to "catch" a bite.



Fig. 14.12 Eating without the aid of knives and forks in one of Caroline Hobkinson's culinary installations. This is reminiscent of Marinetti's (1930/1989) "tactile vegetable garden": one of the courses in his tactile dinner parties.
© Gwangju Biennale Dinner, London 2011, curated by Caroline Hobkinson, photography Lynton Pepper.



Fig. 14.13 Heston Blumenthal's "Hot and iced tea" dish (see <<http://www.thefatduck.co.uk/The-Menus/Tasting-Menu/>> downloaded on September 27, 2012) as an example of visual-oral-somatosensory incongruity in fine dining. Picture downloaded from <<http://thebigfatundertaking.wordpress.com/2010/05/21/28-hot-and-iced-tea-incomplete/>> on September 27, 2012.

It also seems likely that we will see more sensory incongruity involving the oral-somatosensory attributes of food, where the sight of the dish sets up expectations that are incongruent with the experienced oral-somatosensory attributes of the dish (see Piqueras-Fiszman & Spence, 2012b, for a review). Here, one can think about the "Hot and iced tea" dish served at The Fat Duck. The dish looks suspiciously like a normal cup of tea (see Figure 14.13). Indeed, when you first drink from the side of the cup that is proffered to you, the tea is hot as one might expect. However, as soon as you turn the cup around and taste from the other side the drink feels cold! How can that be, the diner asks him/herself? Normally when you pour a hot and a cold liquid into the same glass, the most you could expect to end up with is something having an intermediate temperature (i.e., a drink that is lukewarm).¹⁶

14.7.1 Toward virtual food

In an earlier chapter, we extensively discussed the increased presence of touch in our technology (see Chapter 9). One technological development that is particularly fascinating in terms of the future of gastronomy involves the Virtual Straw (Hashimoto et al., 2007, 2008). This device recreates many of the sensations that you would normally expect to be associated with sucking a liquidized food up through a straw. The researchers concerned have managed to achieve this simply by generating the appropriate sounds and tactile vibrations in the straw whenever a person sucks while the straw is placed over a picture of a particular food. No food is actually delivered, but the illusion is nevertheless still a powerful one. Meanwhile, Iwata (2011) has developed a device for VR environments that generates a force on the user's teeth used as an indication of food texture (by reproducing the force profile captured from the mouth of a person biting inot real food). The integration of this device with auditory and chemical displays allows for the reproduction in VR of a number of food experiences. We believe that the future will see far more examples of the latest in technology being used to enhance (or at the very least to alter) the dining experience. Furthermore, in contrast to molecular gastronomy, where all the new technology tends to

¹⁶ The trick here is the use of a very finely chopped gel that behaves as if it were a liquid. Since it is a gel, hot and cold gel can be poured in either side of a divider placed in the glass, the divider is removed prior to serving, and the two sides, one hot, the other cold, stay separate.

be found in the kitchens/research laboratories, we believe the future will see an increasing move toward technology being present in the front of house when the diner consumes a particular dish (see also Iwata, 2011; Iwata et al., 2003).

14.8 Conclusions

While most of us rarely think about the sense of touch (nor, for that matter, haptics, proprioception, or kinesthesia) when it comes to enjoying a good meal/drink, the research outlined in this chapter has hopefully convinced you of just how important all of the various tactile sensations that accompany the consumption of food and drink are to our overall enjoyment. While the Italian Futurist, Filippo Tommaso Marinetti (1930/1989) was certainly way ahead of his time, the last few years have seen the emergence of a body of research documenting some of the many ways in which touch contributes to, and more importantly, can enhance the consumption experience, be it in a restaurant or some other environment. What is particularly exciting for the psychologist/cognitive neuroscientist interested in the sense of touch, is that artists, chefs, food designers, not to mention cutlery and plateware manufacturers, are now genuinely starting to take such scientific insights on board in the offerings they present to their diners.

Of course, here it is important to remember that touch should only ever be but one part of the multisensory dining experience. The optimal experience will likely involve the stimulation of several (all) senses simultaneously. In this regard, it is interesting to note the Futurists were, once again, way ahead of the field. In the words of Elizabeth David (1987, p. 61), in the *cucina futuristica*: “Meals were to be eaten to the accompaniment of perfumes . . . to be sprayed over the diners, who, fork in the right hand, would stroke meanwhile with the left some suitable substance—velvet, silk, or emery paper.” Such ideas (well, at least the idea of spraying a fragrance over a dish in front of the diner) are nowadays echoed in contemporary molecular gastronomy dishes such as the oyster where an aroma (e.g., of lavender) is sprayed over the diner’s food at The Fat Duck restaurant (see Blumenthal, 2008).

Section E

Conclusions

Touching the future

15.1 What might the future hold for the multisensory perception of touch?

Throughout this book, we have discussed the many different ways in which our brains deal with tactile input. In Section A, we started with a description of what is currently known about the more peripheral mechanisms of tactile information processing, highlighting the variety of receptors and neural fibers that are involved in the transduction of different kinds of stimuli (be they relevant to mechanical or social touch) that come into contact with our body surface. In Chapter 2, we highlighted how much of our experience of touch (take, for example, the feeling of wetness) while introspectively appearing simple and unitary, actually results from a complex interaction between the firing of several different classes of sensory receptors that are present in the skin. In fact, the majority of life's most interesting and important sensations (many of them related to food and sex) result from the integration of the activity of a number of different classes of receptors (in what are known as touch blends). The evidence discussed in Section A demonstrated that tactile sensory integration occurs from the very earliest stages of neural information processing (such as in the somatosensory cortex where information from different skin receptors is first processed). The first section of this book stressed our position that if one's aim is to reproduce believable mediated (not direct) tactile sensations at a reasonable cost (both economically and in terms of the human resources involved), for example, for the realization of VR environments or human-machine interfaces, the dynamics of neural transduction occurring in our skin needs to be fully understood.

In the second part of the book (Section B) we dealt with the more central (cognitive) aspects of tactile information processing. In particular, research on the awareness, attention, memory, and social aspects of touch were all discussed. Time and again, the research outlined in this section of the book highlighted how when the sense of touch is compared to the other sensory modalities some commonalities, but also a number of important differences, surface. That is, certain higher-order systems, such as those involved in directing our attention toward a particular position in space, or in the awareness of events, might actually be shared (at least to a certain extent) amongst sensory modalities. That is, tactile processing (or at least our awareness of the results of this form of information processing) is dramatically affected by the amount of processing that happens to be taking place in the other senses (and this is particularly noticeable following the presentation of visual stimuli). This result should not, perhaps come as that much of a surprise given that the brain networks and areas that are devoted to the processing of visual stimuli are far more extensive and seemingly complex than those involved in the processing of tactile stimuli (see Chapter 3).

The observation regarding the presence of common mechanisms amongst the different sensory modalities certainly contributes to moderating those claims (that have frequently appeared in the applied domain) that touch necessarily provides a viable option in terms of delivering information to an interface operator whenever his/her other senses happen to be overloaded. At the same time,

this observation also clarifies the fact that one cannot really meaningfully study the sense of touch without also considering the processing of information coming from the other senses occurring at the same time. This is probably one of the main messages to come out of the extensive body of literature that has been reviewed in this book. Similarly, in order to fully understand tactile sensations one needs to consider their effect on, and how they are affected by, certain physiological bodily parameters, comprising thermoregulatory control and hormone release (e.g., think about how tactile contact via the release of oxytocin helps to strength some of the most important of our social relationships, such as those that occur within a couple or between the mother and her newborn baby; e.g., Kroeger, 1996; Nagasawa et al., 2012; see Chapter 7).

Beside the similarities between the sense of touch and the other senses, the second part of this book also highlighted how the sense of touch is often constrained by limitations that are much more severe than those that affect the processing of information from the other sensory modalities (or at least the other spatial senses of vision and audition). So, for example, the research outlined in the earlier chapters of this section clearly demonstrated that the ability to process and retain information regarding meaningless, simultaneously presented tactile stimuli (such as random vibrations on the body) seems to be lower in touch than in either vision or audition. These differences might be taken to justify the difficulties that have frequently been encountered by those researchers who have been working on the translation of visual images into tactile patterns of stimulation (see Chapter 9).

Hopefully, the literature reviewed in Section B, but also elsewhere in the book should have contributed to making clear the fact that touch is not only about our perception of what is transduced by the fingertips. That is, despite the fact that the skin is by far the largest of our sense organs (accounting for 16–18% of our body mass; see Montagu, 1971), only a tiny part of it has been investigated in any detail in the past, leaving contemporary researchers with a whole range of undiscovered possibilities (see Figure 15.1). Remember here, that tactile pleasure receptors and nerve fibers in humans were discovered about 20 years ago and that only in the last 5 years has their role in a number of human behaviors started to be fully tested. The potential related to the study of tactile sensations across the entire body surface are only now starting to emerge, given that psychologists and neuroscientists are finally moving their attention toward what have formerly been relatively unexplored regions of the body, such as the arms, the inner thighs, the lips, the feet, the mouth and face, and the genitals. Here, we can't help but be excited at the thought of what else might be discovered by looking to those areas (perhaps even new classes of receptors or neural fibers)!

In Section B, we highlighted that the relatively under-investigated field related to the more social aspects of touch, is likely to be the one that offers some of the greatest potential (as well as technological challenges) in terms of future discoveries and applications. In fact, the latest research now shows just how profound an effect social touch can have on our emotions, as well as our behavior in a number of ways and in a number of situations (see, for example, the growing literature on “The Midas Touch”; see Chapter 7). These effects, although also present at an implicit level of processing (e.g., without us being aware of their occurrence) seems to be strongly modulated by higher-order cognitive factors such as our expectancies and beliefs regarding who it is who is touching us (see Chapter 13). Given that our lives are progressively moving toward an increased presence of mediated interactions (see, for example, the great success of social media such as “Facebook” on the Internet, with more than 1 billion users as of 2012; see <<http://www.bbc.co.uk/news/technology-19816709>> downloaded on October 30, 2012), the resulting lack of social tactile interactions might become an important social issue in the coming years (especially if one believes the many results showing just how beneficial touch is to our health and well-being; see Chapter 7; Field, 2001).

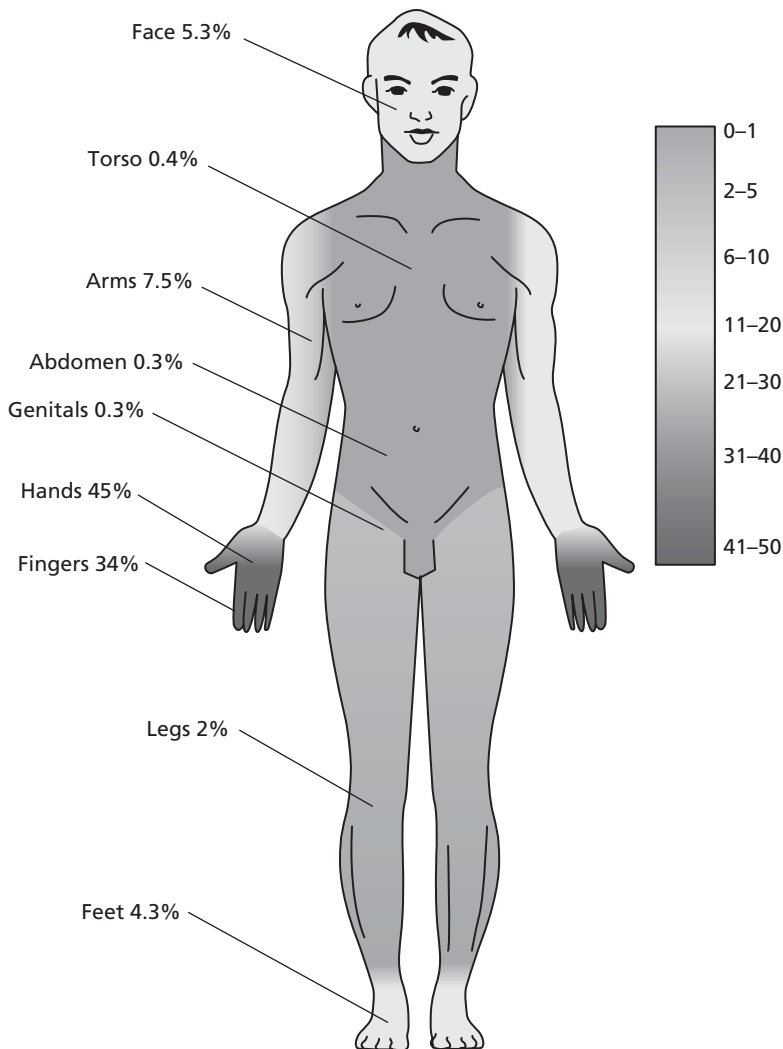


Fig. 15.1 Percentages of studies that have investigated tactile perception on different body parts. The percentages were calculated on the basis of the number of studies published from 1960 to 2012 with the terms tactile or haptic and the name of the body part in the title. Research performed on Scopus on October 15, 2012. The figure clearly highlights that the large majority of the studies on touch have been performed on the hands and fingers.

In the second part of the book, we also considered the large and growing body of research that has recently started to investigate the way in which our brain represents its body. That is, tactile inputs turn out to play an incredibly important role in defining the limits of our self. At the same time, however, the research reviewed here has also clarified that by means of the controlled delivery of tactile as well as multisensory stimuli, it is possible to extend our sense of body ownership to incorporate additional limbs or even entire bodies, no matter whether they happen to be prosthetic, robotic, or virtual. As we saw in Chapter 8, such scientific observations are now starting to open up a variety of interesting scenarios that have so far being envisioned only by science fiction

writers (such as controlling artificial counterparts of our self, or avatars, in order to perform various tasks). Note, however, that the latest evidence from the science lab suggests that these modifications may not come without some cost (albeit hopefully only a small one) in terms of the way in which our brain controls certain vital physiological functions, such as regulating body temperature (e.g., Barnsley et al., 2011; Moseley et al., 2012a; see Chapter 8). Future studies in this field of research will have to clarify the extent to which these costs occur in the absence of any important consequences (or side effects). At present, it seems more like an act of faith than anything else that there won't be any detrimental long-term consequences associated with manipulating neural representations of the body (i.e., to offset the beneficial effects that are already becoming increasingly well established). Thus far, it would appear that our brains have evolved in order to adapt quite well to even important changes to the appearance of our bodies (such as those that occur naturally as a function of our development through infancy) and somatosensory feedback plays a major role in modulating this capability. Nevertheless, the boundaries of this plasticity are still to be fully tested and we cannot say for sure whether it is going to be easier, for example, to incorporate anatomically plausible body parts rather than a "tail," five arms at the same time, or genitals associated with the opposite sex!

In the third part of the book (Section C), we looked at the more applied aspects of touch. In particular, we discussed the relative advantages and limitations (in terms of their compliance with our neurocognitive architecture) offered by a number of tactile devices, such as touch screen, and everything from the regular vibration of the phone in your pocket to the tactile feedback of the ticket or bank automat machine. We also highlighted a number of different kinds of tactile technologies (and their limitations) that are likely present in the operating theatre of your district hospital, the local supermarket, and/or an optional (or possibly standard) feature in the next car that you buy. In particular, in Chapter 10, where we reviewed the use of tactile warning signals for drivers we showed that these signals in isolation seem to be less effective than their auditory counterpart perhaps suggesting that, in this domain, multisensory stimulation is really what is needed (e.g., Spence & Ho, 2008c).

In Section C, we showed that tactile sensations are sought after by those wishing to sell more products or just to improve the quality of a given piece of merchandise (Chapter 11; Spence & Piqueras-Fiszman, 2012). We have also seen that more than ever before companies are now developing new materials or coatings with the specific aim of stimulating our sense of touch, thus resulting in specific experiences and emotions. In this part of the book, we also came to appreciate just how important the sense of touch is to a full appreciation of the food that we eat.

Perhaps some readers may feel a growing sense of unease at the thought of food companies trying to "play" with the oral-somatosensory attributes of our food: after all, shouldn't the preparation of food be all about using good and healthy ingredients (Petrini, 2007)? That is certainly part of it, but still, no matter what our ideas are about what making food should be all about, researchers have demonstrated that food that is specifically designed to stimulate the sense of touch, likely tastes better (even if the ingredients remains the same)! So why say no to improving one of our most pleasurable experiences with the aid of science? Moreover, looking back at the material reviewed in Chapter 14, where we spoke about the role of certain tactile properties of the cutlery or of the plateware that affect our perception of food, the reader might be intrigued by thinking that, surprisingly, until a few years ago, no study had thought to address what are the optimal properties of the objects that enter our mouth in order to enhance our food experience. That is, several times every day, we put in our mouths (one part of our skin with very high sensitivity; see Chapter 2) objects such as forks and spoons that were not necessarily designed in order to be the best for the scope (e.g. Spence et al., 2012). Shouldn't we pretend something better in order

to make the most of our time spent at the table (about 90 minutes a day in the UK and something between 120 and 140 minutes in countries such as Italy, France, and Japan, according to a report published in 2009 by *The New York Times*; see <<http://economix.blogs.nytimes.com/2009/05/05/obesity-and-the-fastness-of-food/>> downloaded on November 2, 2012)?

Finally, and not at all surprisingly, touch (also by means of its effect in the release of hormones), has been shown to play a crucial role in our sexual behaviors, even if relatively little research has been performed on this aspect of touch so far. Actually, as far as we are aware, this is the first book on touch where the scientific aspects of two of life's "most pleasurable" activities, sex and food, have been addressed seriously/scientifically. This is where much of the pioneering research on the sense of touch is taking place currently, and where the most exciting findings may well emerge in the coming years.

We believe that any serious piece of scientific research will likely generate more questions than answers in the quest for knowledge. At the end of this book, there are certainly many more questions still awaiting a response than answers that have been provided by those researchers working on this once "neglected" modality (especially when compared with vision). Even with a great effort it is difficult to summarize all of them in this section of the book. In this final chapter, we decided to concentrate on the future, highlighting a number of the most exciting directions that tactile research might follow in the coming years. That is, what fields of study are likely to offer the most important insights in terms of the functioning of this amazing sense? What kind of tactile experiences should we all expect to find in the marketplace or in other domains of our life in a few years' time? What exactly does the future of touch hold for us?

It is certainly difficult to make predictions in such a fast moving field. However, technological, economical, and scientific advances are based on predictions about what the future (be it next year, or a decade from now) will be like. Therefore any such attempts in this direction should always be made with caution and in the full recognition that there might be a chance that they won't be any more successful than those that have been made in the past. In fact, the reader has seen throughout this book, that the majority of the predictions about the future of touch that were made in the past ended up being unfulfilled, leaving those making the suggestions wondering why they got it so wrong (assuming, that is, they believed to their own prediction in the first place). As far as this point is concerned, we should acknowledge that many of the still unfulfilled predictions (such as those regarding the existence of tactile television—e.g., Collins, 1970—or the imminent arrival of the multisensory cinema, e.g., Heilig, 1962) were made during what can be defined the infancy of contemporary research on the sense of touch. That is, in the early days of tactile research, when technology and touch first started to come together, it was rather difficult to build upon previous experiences, and to learn from previous mistakes, just because, at the time, there was little, if any, relevant research on this topic. By contrast, more recent predictions, especially in the applied domain, have often not been realized because they simply failed to consider our current scientific knowledge on touch (one might think, for example, of the claims about the majority of people having a "second life" on the Internet or also about the success of hugging t-shirts; see Chapters 7 and 9). In particular, many of the predictions went unfulfilled because they did not consider the ways in which our brain processes and integrates information from the different senses (and, in particular, the problems encountered by those researchers who have worked on these topics). Here, once again, we would like to stress the fact that any prediction regarding the future of touch might have a much better chance of being fulfilled (or of resulting in technological and/or theoretical advances) only if based on what we know about the limitations and characteristics of our neurocognitive system when viewed in a multisensory setting. In particular, when it comes to developing new devices or technologies that human beings have to use or interact with,

it is wise (at least if one wants to have a competitive advantage in the marketplace) to invest in those ideas that are well grounded in the field of neurocognitive research. So what are the predictions that we can make on the future of tactile research?

From a theoretical point of view, there are fields of research on touch that are at the moment clearly under-investigated, although offering seemingly great potential in terms of rapid advances in the future. In particular, throughout this book, we have seen that most of the extant research on the sense of touch has been concentrated on only a few regions on the body surface, namely the hands and especially the fingertips (see Figure 15.1). We certainly expect more research to be conducted on other body parts, and even on how stimuli presented on different body parts interact when delivered together. The research that has been conducted over the last few years has started to investigate the role of certain neural fibers, the CT afferents, on the more pleasant aspects of touch. We believe that research in this area will continue to grow, driven also by our constant search to create objects and experiences that are more “beautiful,” pleasurable, and even sensual not only to our eyes but to each and every one of our senses (Postrel, 2004). In fact, it is not difficult to acknowledge that the “aesthetics of touch” (if philosophers could agree that tactile sensations can be considered “beautiful” in their own right), is one of the less developed fields in cognitive neurocognitive research.

A theme that somehow represents the opposite face of pleasure is pain (even if philosophers can't decide whether pain should be considered as a part of our sense of touch or a completely different modality of experience). We have not directly dealt with the topic of pain, but at several points in the text, the research that we have been reviewing has shown that pain and touch are similar in a number of regards. Moreover, recent studies would appear to suggest that some modulatory factors that have been found to be successful in affecting tactile perception are also effective in terms of altering our ability to perceive pain (e.g., Gallace et al., 2011c). That is, one might exploit the knowledge that we now have concerning tactile information processing in order to understand, and eventually to treat pain, in a number of clinical conditions (see, for example, the discovery that the perceived intensity of pain and touch are decreased when we cross our hands; or that pain is reduced by watching the affected part of the body through minifying glasses; Gallace et al., 2011c; Moseley et al., 2008b). This is certainly another area where research is likely to make important steps in the future. What is currently urgently needed is to conduct longer-term follow-up studies to assess the beneficial effects of the most promising of these psychological interventions.

Another important field of research that will likely flourish over the next few years is related to the link between modifications of our body representation, the reproduction of tactile sensations, and the development of mediated environments. Over the course of the last two decades, there has been a very sharp growth in VR. However, as we have seen at numerous points throughout this volume, the majority of economical and human resources in the development of technologies in this area have been spent on improving the visual and, to a lesser extent, auditory quality of VR. Nevertheless, we have also seen that from the point of view of the functioning of the neurocognitive system, this is not necessarily the best approach to take when it comes to improving the performance of a human interface operator. In fact, despite its very high costs, the benefits that it provides, in terms of enhancing a user's sense of presence or even only his/her perception of the simulated environment, are ridiculous. By contrast, adding tactile contact to VR interactions represents one of the more promising approaches when it comes to delivering greater benefits, especially in terms of enhancing the operator's sense of presence. That is, the benefit/cost ratio would seem to be higher for touch than for vision! We believe that VR systems for a number of applications, from training surgeons to prototyping new objects, will push research on the reproduction of tactile sensations. Given that human performance would seem to benefit from the

possibility of watching one's own body (e.g., Cardini, Longo, Driver, & Haggard, 2012; Fiorio & Haggard, 2005; Kennett et al., 2001), future VR applications will likely make more and more use of a virtual counterpart of our self. This might also lead to the creation of what we have called “functional virtual prostheses”; that is, virtual body parts or instruments that modify (even radically) human anatomy and extend its functionality. Given that technology in this field is far from being effective when it comes to reproducing tactile sensations, we believe that a viable option will be to use multisensory signals and illusions in order to trick the brain into perceiving tactile sensations even where they are not actually delivered or rather when they are oversimplified as compared to the stimulations to be reproduced (such as when using sound to increase the dynamic range of touch screens; see Lee & Spence, 2009).

Tactile research will also continue to grow in the applied field toward the development of novel technologies that will increasingly come to affect the way in which we live. In particular, we believe that tactile augmented reality (AR) is likely one of the fields where the largest progress will be made. In fact, by means of this technology people will likely be able to watch objects on a PC screen or even on a shop window, and have a “tactile glimpse” of them before buying or trying them on. It doesn't seem likely though that this will become a reality any time soon, given the enormous problems that research in this field will have to face (from the limitations of bandwidth, to that on our knowledge regarding the blend of sensory attributes and neural activations that contribute to eliciting certain experiences). In the meantime, we believe that the need for tactile sensations will be fulfilled only by allowing consumers to touch the real objects (at least when possible) on display while they shop. This is actually happening right now, with more and more shop chains inviting their potential customers to come inside and touch the merchandise (and/or to interact with their touch screens).

In the years to come touch will also become an increasingly important aspects of what we happen to wear. In fact, while tactile attributes have always been considered important aspects of clothing, there is now a growing wave of interest in integrating various technologies in garments (see Ho, Jones, King, Murray, & Spence, 2013; Quinn, 2012). This can go from having some kind of tactile or haptic devices inserted in our clothes (wearable interfaces) or rather wearing clothing that have been explicitly designed in order to elicit particular emotions and sensations by means of touch and multisensory stimulation (something that Marinetti suggested nearly a century ago; see Chapter 14; see also Balla, 1973, for a Futurist manifesto of clothing). An example of the latter trend, which has recently been named “enclothed cognition,” is represented by the work of Adam and Galinsky (2012). They had participants perform a selective attention task while wearing a scientist's white coat or rather their own clothes. Those individuals who were wearing their own clothes made twice as many errors as the other participants. That is, the clothing that we happen to wear can apparently play an important role in affecting our behavior and cognitive processing (perhaps something that won't come as any surprise to many fashion designers or dedicated followers of fashion). Following on from such observations, one might imagine that the interactions between proprioceptive, vestibular, tactile, visual, olfactory, and auditory information might contribute to making a woman feel more attractive while wearing high heels than a pair of comfortable slippers! Research in this frontier field of enclothed cognition will likely disentangle which tactile and multisensory aspects are responsible for these changes to occur.

As should have been clear from Chapter 14, we have no doubt whatsoever that food research and gastronomy is one of the fields that will likely make the most from the study of touch in the years to come. As mentioned already, many food companies are investing in this sector. What is more, a growing number of chefs are now increasingly coming to realize the importance of manipulating the texture of a food in order to elicit certain perceptions, emotions, or even whole experiences.

Perhaps the next time that we munch on a potato chip we will be thrilled by the thought of how much scientific research has been put in it to make it so crunchy or tasty! Somehow similarly, a trend has emerged among food (as well as other merchandise) companies to create and protect “signature feels” that are as identifiable as today’s trademarked branded logos and brand colors.

As far as the more social aspects of touch are concerned, we believe that the trend toward there being less and less tactile contact in our society today (especially for the growing aging population) identified by Field (2001) is unlikely to stop. That is, just as people in ancient times banned for good the use of the hands for eating their food, it is likely that less physical contact will be tolerated by modern society. As we have seen, this is already occurring, with all the negative consequences that it carries in terms of our well-being. We should be especially preoccupied about these detrimental effects after having discovered specific tactile fibers involved with the perception of pleasure; see Chapters 2 and 7. At the same time, it is also likely that, driven by the extant research, people will finally start to realize just how important tactile social interactions are to many domains of their life. So how to reconcile these two apparently contradictory points of view? Our opinion is that technologies that are capable of providing believable surrogates of real tactile social contacts will likely become a part of our future lives. In particular, research on tactile-mediated interactions (that are able to fill the need for touch that at the moment seems to slow down the development of virtual social environments) will likely attract more researchers and investors in the years to come. However, one should not forget the great challenges that will await them along the way. These challenges are witnessed by a number of recent studies showing that certain effects of social touch (such as “The Midas touch”) have been found hard to reproduce within mediated environments (see Chapter 7). We believe that major progress in this field will be determined more and more often from the realization that is not really important what a person is actually feeling (or how much a pattern of stimulation resembles the stimulation that can be obtained in a real context), but what a person “believes themselves to be feeling.” That is, if your brain identifies a tactile stimulation as real, it is real, no matter what was used (in terms of physical or neural stimulation) in order to create it.

Moreover, in order to be successful, researchers will also need to consider that believable mediated tactile contact will likely need to be completed by the presence of other sensory cues that go beyond vision alone (e.g., olfactory). That is, here one might certainly claim that the future of touch cannot be anything but “multisensory!”

Finally, as the following quote by Paul Bloom, psychologist at Yale University and author of a recent book on pleasure (Bloom, 2011, p. 89), would seem to suggest, the field of mediated sexual interactions is probably likely to be the one that will benefit most from the progress currently being made in tactile research. As Bloom puts it: “If I were the sort to invest money, I’d invest in that [teledildonics], because I imagine that such an activity, if the technology could be made workable, would be immensely popular” (pp. 88–89).

In summary, in this book, we have tried to highlight the importance of touch as a sensory modality, one that for many years has been neglected by the majority of researchers in the field of perception research, but one that affects every aspects of our life. We have also highlighted that the increase in our understanding on how our brain works together with our growing ability to realize cheaper and more effective technologies makes this a very exciting time (right here, and right now) for genuine progress and opportunities on touch to be achieved. From eating to walking, from typing to kissing, from texting to cuddling, the majority of our everyday experiences require a great deal of tactile processing. Moreover, touch contributes to make us perceive that the sum of muscles, bones, and tissues that create the human anatomy, is actually “our body,” well detached from the external world. This book has also clarified that understanding the functioning of our

tactile systems and the way in which our brain deals with tactile sensations, is vital to engineers and designers waiting to create more enjoyable experiences in every domain of our life. That is, optimal design will come more and more often from reverse engineering the functioning of our mind! In conclusion, we believe that the future holds amazing possibilities for tactile research, especially if more investment (not only economic but also human) will be attracted by its immense potential.

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