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PSYCHOLOGY OF TOUCH AND BLINDNESS

Morton A. Heller and Edouard Gentaz

Psychology of Touch and Blindness

This book reviews the considerable body of research that has been done to evaluate the touch skills of blind people. With an emphasis on cognitive and neuroscientific approaches, it encompasses a wide-ranging discussion of the theoretical issues in the field of touch perception and blindness.

The volume includes chapters on sensory aspects of touch, perception in blind individuals, multimodal relations and their implications for instruction and development, and new technology, including sensory aids and virtual touch. A distinctive feature of the book is the inclusion of the practical applications of research in this area.

A significant characteristic of research on touch and imagery in congenitally blind individuals is that it speaks to the basic nature of spatial imagery and the importance and necessity—or lack thereof—of specific visual sensory experience for the acquisition of knowledge about space, spatial layout, and picture perception. As such, the book will not only appeal to researchers and professionals with an interest in touch and blindness, but also to a wider audience of cognitive psychologists and cognitive neuroscientists working in the field of perception.

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Preface

We are very optimistic about the advances that will be forthcoming in research on touch perception. The field has been growing, with the advent of new societies that devote much of their effort to studying touch in a variety of contexts. For example, Eurohaptics is a relatively new society that derives membership from the engineering, robotics, and more traditional academic communities engaging in research on touch. Also, the Multisensory Research Forum is a growing society with many members concerned about the relationship between vision and touch. Finally, a section of Scholarpedia is devoted to research on touch (http://www.scholarpedia.org/article/Encyclopedia_of_Touch).

Advances in the field are likely to have important implications for rehabilitation in blindness, but also in a number of other areas. Robotics is one area that is likely to see large advances, as is the field of virtual reality incorporating touch sensations. In addition to providing entertainment, advances in haptic virtual reality will have a large number of biomedical applications. The development of useful prosthetic devices depends on advancing our knowledge of sensory function as well as engineering. This is an exciting time to be involved in research in touch, and we expect to see a great deal of useful research in the immediate future.

We have learned a great deal about touch in the past few decades. There has been substantial progress in neuroscience and in our understanding of the physiology of sensation. However, there is a lot of room for further growth of knowledge, if we learn to ask the right questions.

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1 Introduction

Historical and Philosophical Background

Touch is a remarkable sense and is unique in a number of ways. It allows us to experience an amazing and wide variety of sensations. Some of these are delightful, but some are really unpleasant. Information derived from touch is essential for our survival, and the world would be a very dull place without the pleasures that we experience using our sense of touch.

Touch comprises sensory and perceptual elements, and both will be discussed at length in this volume. As a sensory system, we can feel hardness, softness, and a number of primary qualities of objects (Locke, 1689/1975). These primary qualities are important for a number of reasons, but we would be hard pressed to survive without the ability to "feel" our surroundings. Touch also imposes a number of sensations that can have emotional impact, and these differ in many ways from the sorts of sensations that we can experience through olfaction, gustation, or vision. It is difficult to imagine the "feel" of the odor of a rose, for example. Conversely, I cannot conceive of how one can truly "visualize" the pain induced by an abscessed tooth in need of a root canal.

Touch has many remarkable qualities as a perceptual system, and these will be emphasized in this volume. While such topics as pain will be covered, more discussion time will be devoted to the perceptual aspects of touch.

The organ of touch is unique in comparison with the other senses. Our sense of touch is dependent upon our skin, obviously the largest sense organ we have. In addition, touch sensibility is dependent upon the musculature and underlying tissues. The touch "organ" continually changes in shape, and this is radically different from other sense organs. Our eyes are relatively constant in configuration, as are our other senses. Of course, the nose changes somewhat as one "sniffs" and the eyes may squint or narrow. However, these changes are not nearly as dramatic as the changes that generally occur in body configuration. The variability of the structure of the sense of touch is a strength of the haptic perceptual system, but this also represents a practical challenge to researchers.

We feel things with our hands, but we obviously can feel with all of our body components. I can feel the floor beneath my feet as I walk, and I feel the chair that I sit on. For example, while eating corn on the cob, I can feel it with my mouth (teeth, tongue, and lips) and both hands. While I generally ignore the feeling of clothing on my skin while engaged in other activities, I am sure that I would notice it if my clothes were to suddenly vanish while teaching a class!

Much of the study of touch has involved the hands, although many developmental researchers have been interested in oral touch. Infants spend considerable time "mouthing" objects and sucking on them (Bushnell & Boudreau, 1991). However, we feel objects with all parts of our bodies during the course of a day. I can feel my dog brush up against my calf, for example, and I can feel my leg against my desk as I write this manuscript. Physical contact with the world is a perceptual background that is always present, whether or not we devote much conscious attention to this perceptual experience.

Historical Background

Interest in the sense of touch has a number of important roots, including philosophy, clinical neuroscience, cognitive neuroscience, psychophysics, engineering, and, of course, the important consequences of a lack of touch sensibility in diabetic neuropathy. Of great interest has been the impact of visual loss on how we rely on the senses, particularly the sense of touch.

Clinical Roots

Diabetes may all too often cause a loss of vision, and is a very common cause of blindness. It also may lead to neuropathy, and a loss of touch sensation in the hands and feet. These sensory losses can promote peripheral damage to organs. It is all too easy for a person to damage the skin, if he/she cannot feel how pressure is applied when manipulating objects. A similar loss of tactile sensation occurs with leprosy.

Very dramatic tactile sensory loss can take place with spinal damage. Morton Heller has known an individual who was paralyzed and also suffered sensory loss from spinal damage owing to trauma from penetrating wounds. This person developed bedsores and died of infection at a relatively early age. It is difficult to survive when mobility and touch sensations are severely compromised.

Brain damage can often yield unfortunate clinical symptoms, and these are apparent in alterations in touch. People may experience chronic pain. Inappropriate pain experiences can be related to alterations in one's body image, as in phantom limb pain (Critchley, 1953). Here, a person feels pain in a limb that has been amputated. Furthermore, peripheral neural damage can yield pain experience, when one might expect to feel normal touch. These protopathic pain sensations can cause considerable distress. Also, people with fibromyalgia feel pain upon light touch to the skin, and this can make them miserable.

Central nervous system damage can produce alterations in tactile perception that can be very disturbing. People may feel phantom limbs where no limb has ever existed (Critchley, 1953). These symptoms involving a body image disorder can occur along with epileptic seizures or by themselves. For example, some individuals may feel an arm coming out of the middle of their chest and even feel it wiggle.

Jonathan Cole described the case of Ian Waterman, who suffered a complete loss of tactile sensation over his entire body below the head (Cole, 1995). This extremely rare neurological disorder may have developed from a viral infection. Whatever the cause, Waterman collapsed when trying to stand up one morning. He was unable to move or feel anything. The impact of the loss of touch was devastating. He had to learn, over a relatively long period of time, how to use his sight to control movement of his limbs and manipulate his body. The loss of touch can be deadly, since tactile and pain sensations serve to preserve us by warning of danger. The sense of touch is often ignored by many of us, and we take it for granted. We would not take touch for granted if we were unable to feel anything. Loss of tactile sensation can also derive from causes that do not involve neural damage. While not very common today, many of Freud's patients presented with glove anesthesia, where they had a loss of sensation on both of their hands, as if wearing gloves. Fortunately, leprosy is now rare in the United States and Europe but still occurs in third-world countries. The disease compromises tactile sensation in the face and extremities. Without the ability to sense pain or pressure on the skin, it is all too easy to inflict damage on oneself.

People can learn to compensate very effectively for a loss of vision or of hearing. While none of us who rely on sight or hearing wants to go blind or deaf, people may live relatively "normal" lives without sight. Blind people shop, travel, and do all of the things that the rest of us do. One can argue that they may benefit in some ways from an inability to "watch" television. However, some tasks that we accomplish using sight are more difficult to do with touch. Reading Braille is slower than reading with one's eyes, and society does not make things very easy for people who are visually impaired. Walking in traffic is fraught with danger for any of us, but the danger is increased for people without sight.

There are some striking differences between the operation of touch and vision, and this has complicated our understanding of the sense. Of course there are similarities, and these will be discussed in this volume. Touch is intimately linked to movement. Unlike vision, haptic examination of a surface or object can alter it. Haptic refers to an active exploration of objects using intentional action (Gibson, 1962). For example, if one picks up a cat or dog and strokes it, this action changes the visible and tangible configuration of the object. Certainly, looking at one's dog can alter its behavior and induce some transformation in the configuration. But if one feels a person's face, this action alters the flexible aspects of the object, namely the muscles and skin. The underlying skeletal structure is not altered, assuming the mouth is not opened or closed. If one feels an object that is flexible or malleable, the shape of the object changes. Looking at another individual or object never produces precisely the same sort of transformation.

Blindness

Researchers have come to this research area because of theoretical and practical concerns about the impact of blindness on individuals. The loss of sight poses a number of problems for people, since they have to learn new mobility and communication skills. Blind people must show increased reliance on the sense of touch, and they provide a unique study sample for interested researchers. Blind individuals may have been born without any sight, and these congenitally blind (CB) persons reveal the ability of touch to perceive forms or object characteristics without the influence of visual experience or visual imagery. Most sighted individuals spontaneously report producing visual images while they feel objects. Some even indicate that they spontaneously close their eyes behind blindfolds while engaging in haptic exploration of pictures or maps. Moreover, people who lost their sight later on in life, the adventitiously blind, or late blind (LB), also say that they can remember how things look and may experience visual images while they feel objects (Heller & Ballesteros, 2006).

Many researchers have assumed that the presence or absence of visual imagery is critical and has a great influence on haptic perception in blind individuals. For example, Lederman, Klatzky, Chataway, and Summers (1990) explicitly assumed that touch is best at perceiving the material qualities of objects, namely hardness, softness, weight, and so forth. Geometrical properties, they argue, are more appropriately perceived via sight, and touch requires visual mediation in order to judge form most adequately. Note that it is easy to recognize familiar objects by touch (Klatzky, Lederman, & Metzger, 1985). Indeed, if one could not identify familiar objects by touch, this would be a sign of significant brain damage (Critchley, 1953). One might expect that visual imagery and visual mediation would be lacking in CB individuals. Consequently, this may explain some reports of lower performance by CB persons in picture naming tasks (Heller, 1989a). This issue will be taken up at greater length at a later point in this volume, but there is a large amount of literature showing the benefits of visual imagery for memory in sighted individuals (Paivio, 1965). However, it must be noted that there are many differences in the backgrounds of CB persons and other individuals besides visual imagery and visual experience. Educational experience differs as a function of vision or lack of it, as does prior experience with tangible pictures. The use of 2-D illustrations is often lacking in the educational background of many blind people. It is entirely possible that deficiencies in the education of people who are visually impaired, rather than an absence of visual imagery or visual experience per se, plays an important role in the data that are present in the research literature.

There are important applied and practical concerns in the area of blindness rehabilitation. Blind people require instruction in the use of touch for mobility, reading, and communication. The consequences of early versus late onset of blindness have implications for rehabilitation and education. If an individual loses sight at birth or in early childhood, there may be reduced opportunities for learning about some academic areas, such as mathematics or geography.

This is the case because tangible illustrations are infrequently available in text material. However, the CB child has probably had considerable education in mobility and a lot of experience with using touch for pattern perception involving Braille. People who lose their sight later in life or in old age are unlikely to be willing or motivated to undertake the considerable time and effort required for learning these important skills. Furthermore, increased practice using the sense of touch for pattern perception in blind individuals could explain their superior performance in a number of tactile spatial tasks (Sathian, 2000). Sighted individuals certainly use the sense of touch while wielding objects or manipulating them. It would be impossible to drive if one could not feel the steering wheel as one drives a car down the road. However, sighted individuals more often use touch to manipulate objects, rather than for pattern perception. We most frequently rely on our vision to make judgments about object geometry, spatial relations in the world, mobility, and for reading and using computers. It is in these sorts of tasks that blind individuals have increased experience using the sense of touch.

Pictures have played a minimal role in the lives of most blind people in the United States, and many other places in the world. The frequent assumption has been that pictures are for sighted people, but not for individuals who are blind (Heller, 2000a). Heller has heard more than one blind person say "*. . . you are trying to make blind people think sighted*" in the midst of a research study (p. 757). This negative attitude about the value of pictures for blind people may derive from a general bias within our society and the educational community. Whatever the source, negative expectations tend to be self-fulfilling prophecies and may compromise the interpretation of the results of research in this area. The practical implications of a lack of exposure to pictures and illustrations can involve disastrous limitations in educational experiences for blind individuals. This issue will be taken up at a later point in this volume.

A number of theoretical perspectives have assumed that haptic perception is not capable of good performance in the perception of tangible pictures. If this were true, it would require a very negative prognosis for the value of pictures in the rehabilitation of blind people, and for their understanding of space. However, the research literature suggests greater optimism than older research in the area would suggest (Heller & Ballesteros, 2006; Heller et al., 2009).

Philosophical Roots

The study of touch has a number of philosophical antecedents, and this chapter will not attempt an exhaustive examination of them. However, the present state of knowledge and research in the field has been greatly influenced by the work of philosophers, and this background should be discussed.

Rock and Harris (1967) described Bishop Berkeley's purported claim that touch educates vision over the course of development. Visual images change apparent size as one approaches or moves away from an object, and visual angle becomes an unreliable clue to size or distance for unfamiliar objects.

Thus, if infants lack innate knowledge of how to interpret what they see, and cannot judge size and distance accurately, how are they to know whether the changing image of a parent who is approaching is growing larger, or is actually approaching? Berkeley discussed the notion that we learn to interpret visual images by way of an association with our own movement and mobility in the world. However, Berkeley (1709/1974) argued that we never really "see" distance, since it is an intellectual sort of judgment, rather than a perceptual judgment. Thus, we come to learn that the smaller image size of a person at a distance means that the person is far away, but we do not directly "see" this.

Philosophers have long been interested in blindness and what it can tell us about perception and the relationship between vision and touch. John Locke (1632–1704) was particularly interested in William Molyneux's (1656–1698) question (a letter sent to JL on 7 July 1688; cf. Morgan, 1977; Wade & Gregory, 2006), namely what would happen if a person who was born blind suddenly had sight restored? Thus, if a person who was limited in life to feeling a cube and sphere and never saw them, suddenly had vision restored, would the person know how to name these objects upon first seeing them? Would the individual immediately know how to interpret what she or he saw, or would learning be required? The empiricist response from Locke is that learning would be needed. However, one might think that some simple aspects of the geometry of objects, namely curvature or angles, would be comprehensible from a nativist perspective, emphasizing innate processes.

Gregory and Wallace (1963) have provided important insights into this issue in their description of an individual who had sight restored in middle age. Richard Gregory's description indicated that many aspects of visual space were incomprehensible to this middle-aged person after surgical restoration of vision. Depth, perspective, and other aspects of our typical visual experience were confusing. The restoration of sight was of little benefit to a person who was competent as a blind person, but not functional as a sighted one. Important visual perceptual skills were lacking, including visual object recognition, reading, and visual skills related to mobility. Thus, restoration of sight turned a well-adjusted competent (blind) person into one who was illiterate and had great difficulty functioning in the world as a sighted individual. The surgical intervention was not very helpful to this person. Indeed, one older CB individual once told Heller that if it were possible to restore his sight, he wouldn't want to do it. He was functioning perfectly fine in the world and did not relish the idea of this sort of radical transformation. Just as sudden blindness late in life can be difficult to cope with, the reverse can be true as well.

Marius von Senden (1960) described a large number of cases of the restoration of sight. Unfortunately, it is difficult to know how to interpret many of them. A typical case involved cataract surgery, but earlier methods dating to von Senden's time did not provide clear indications about an answer to Molyneux's question. After cataract surgery, an individual's vision was not normal for some period of time, since the older procedures were very crude and required large incisions, substantial trauma, and a long recovery period. Large incisions were required for cataract surgery more than 15 or 20 years ago. In addition, it was often the case that the examination of patients occurred a considerable time after restoration of sight. Currently, cataract surgery may lead to excellent vision on the same day as the procedure, but surgical advances have been dramatic over the past few years.

Weber, Katz, and Revesz: Historical Roots

Ernst Heinrich Weber has had a significant impact on current thinking and research on sensory processes in touch, despite the fact that much of his work dated from 1830–1850 (Weber, 1978). His description of sensory circles anticipated current thinking on receptive fields. Weber's research was modern and timeless.

Weber made a number of interesting observations and empirical contributions that are well worth describing. Weber remarked that touch is much more effective when people engage in intentional action, and distinguished between touch and the muscular sense. In addition, Weber noted that active movement by the hand aids weight perception. He reported laterality effects, with greater tactile acuity on the left side of the body in most, but not all of his participants. He also used the two-point threshold as a measure of tactile sensitivity and found that the thresholds were more distinct along the transverse axis than the longitudinal axis of our bodies. Weber thought that extents were perceived as greater on body parts that were more sensitive, anticipating more contemporary findings (Cholewiak, 1999).

Weber was also interested in touch illusions. Interestingly, Weber found that a flat plate can feel convex or concave when pressed on the skin. The impression of curvature depends upon the sequence, direction, and dynamics of movement. According to Weber "a smooth glass plate pressed at first weakly, then strongly, then weakly against the finger-tip seems to have a convex surface" (1978, p. 54). If the sequence is reversed so that the plate is first pressed strongly, the plate is felt as concave, according to Weber. He also commented on the Thaler illusion, in which a cold object feels heavier than a warm object.

David Katz was a Gestalt psychologist, who made a number of fascinating observations about touch (Katz, 1925/1989; Krueger, 1982). Katz was very influential in haptic research and had a great impact on both George Revesz and J. J. Gibson. He was especially opposed to research on touch that treated the organ of touch as the skin and that immobilized it for psychophysical experiments. Katz objected to the atomism in sensory psychology. Thus, Katz stated, "The atomism in sensory psychology that we have fought against in this book is also the result of such a procedure" (1925/1989, p. 229). Katz was here referring to the adoption of theoretical perspectives without first examining the evidence. He objected to limiting research on touch to psychophysical methods, since he thought that they were artificial and atypical. According to Katz, in very critically describing psychophysical methods:

> Thus, just as the excitation of single, isolated sensory organ, e.g., a pressure point, occurs in an artificial way, so too, the resulting state of consciousness

> is also not a natural growth . . . . To produce such experimental conditions means devising situations so extraordinarily remote from natural stimulus conditions that even the absurd, multiform accidents of everyday life would hardly ever lead to such situations and thereby to a sharply isolated stimulation of a single sensory element. Most people may die without ever having experienced the triggering of an isolated pressure or warm point or a genuine two-point threshold. (1925/1989, p. 35)

Katz, as with many other theorists, emphasized the intimate involvement of visual imagery in touch and thought that it was responsible for giving it spatiality. According to Katz, "Therefore, in the construction of these modes of appearance, we regard everything specifically spatial as having been imparted by vision" (1925/1989, pp. 60 & 229). Touch, according to Katz, is especially useful for providing information about the material properties of objects, namely their thickness, roughness, smoothness, and hardness. He emphasized the role of vibration in texture perception.

Katz stressed the role of the intelligent hand and active movement in haptic perception. According to Katz, touch has objective and subjective poles. The objective nature of touch is revealed when we engage in active, purposive movement. This allows us to perceive objects "out there" in the world, rather than on our skin. Passivity promotes subjective experiences and sensations on the skin surface. Both objective and subjective experiences occur in touch, but presumably we should not confuse them. Thus, the prototypical subjective experience involves pain. If we say, for example, the needle "hurts" when we receive an injection, we know that the pain is in us and not in the needle. While Katz stressed the role of the hand in touch, he noted that other body parts can feel objects, namely the lips, teeth, and even the toes. He didn't think that one can feel texture with the toes, but surely this is incorrect. When walking, we can and must distinguish between slippery and rough surfaces and modify our walking to avoid falls (Katz, 1925/1989, p. 140).

In addition, Katz distinguished between surface touch, immersed touch, and volume touch. We feel a continuous surface when we move our fingers over one, even though there are gaps between the fingers. Immersed touch is experienced when we move our body parts through liquids. Katz also described volume touch, in which we feel 3-D objects through a transparent medium such as a cloth. Physicians employ this form of touch when palpating a patient's chest.

Revesz (1934, 1950) has had a profound impact on the study of touch in the sighted and in blind individuals. Some of his observations were astute and prompted advances in the field, but some were far less helpful. Revesz also emphasized a distinction between active and passive touch, and also thought that haptics functioned very differently from vision. These distinctions had significant implications for the evaluation of perceptual skills in blind people, and in their possible appreciation of graphics and form.

Revesz viewed the hand as the organ of touch, and this is hardly surprising. He proposed that touch tends to comprehend form in a successive manner, while vision operates simultaneously. In addition, he assumed that touch is generally active, intentional, and purposive, and this leads to an impression of form that is more "cognitive" than perceptual. Thus, form is not immediately perceived via touch. The stereoplastic principle is the idea that when we are confronted by objects, we will tend to enclose them and grasp them in order to know them. The kinematic principle refers to the idea the movement matters, and passive touch may often be poor. Revesz thought, as with Berkely, that the hand provides a measurement metric for judging the size of smaller objects.

Revesz described a number of methods of feeling forms, and these descriptions may foreshadow more modern theoretical formulations about exploratory procedures (Lederman & Klatzky, 1987). Touching may involve to-and-fro gliding motions, and this is an attempt to gain knowledge about the material properties of objects. These properties include variations of the surface and texture. Sweeping motions can involve the entire hand or may be limited to the index finger. These sweeping motions are designed to discover planes and discontinuities, as well as small details in a surface. There is also a sweeping-grasping form of touch that is transitional to the normal grasp. This allows the individual to touch multiple surfaces of an object with the help of the thumb. "Kinematic grasping" touch permits the apprehension of the structure of objects. Revesz also described a type of "holding-touch" that is intermediate between active and passive touch and allows the pickup of information about volume and weight. Note that he thought that without movement, it is impossible to recognize objects or their qualities.

Revesz thought that art was restricted to vision, because of the limitations of haptics. Revesz argued that form played a small role in haptics and that "The blind show very little interest in form" (1950, p. 75). Thus, global form was only recognized visually, and he claimed: "It is therefore not surprising that a genuine art of the blind does not exist" (1950, p. 74) According to Revesz, the late blind are more interested in form than those who are congenitally blind. Furthermore, he proposed that art is visual (but see Axel & Levent, 2003), while tool use is haptic. The argument about blind people being uninterested in form was supported, according to Revesz, by the failure of blind people to accept embossed print and the subsequent success of Braille.

Thus, the impact of Revesz on research in touch and blindness has been mixed. His emphasis on the active nature of touch and tool use has likely influenced more recent researchers from the ecological perspective. However, his negative comments on the perceptual abilities of blind individuals have not been especially helpful to their education or rehabilitation. Later chapters in this volume will examine the empirical evidence on this controversy.

Gibson's Ecological Psychology

J. J. Gibson (1966, 1979) had a substantial impact on research in touch. His major emphasis involved a concern that in attempting to exert experimental control, researchers could eliminate a number of important variables from experiments (Brunswick, 1956). Thus, research may involve an artificially constrained and inactive perceiver, with an immobile hand. The ecological perspective assumes that we should examine a sense in a relatively normal, or ecologically valid context. People do not generally exist without movement, even in a vegetative state. They normally move continually and reach out to touch objects with purpose. This view contrasts with a trend towards following the lead of Weber, and testing perceivers by poking at the skin with devices to measure cutaneous sensitivity. Also, many traditional researchers in the field have used sophisticated instrumentation, and this often requires delivering a vibrotactile stimulus to the stationary skin.

In a seminal early work, Gibson argued for a fundamental distinction between active and passive touch (Gibson, 1962). There is little doubt that Gibson was influenced by both Katz and by Revesz (Gibson, 1966, p. 116). Touch is passive when the observer does not move and an object is imposed on the individual or organism. This sort of stimulation can be artificially delivered in the laboratory or through dynamic events in the real world. Thus, one can push a point, two points, or grooved stimulus into the skin and ask for psychophysical judgments. In a natural environment, a cat can push against us. Alternatively, an insect like a bee can land on one's arm and perhaps trigger an inappropriate swatting response. According to Gibson, passive stimulation of the skin often promotes subjective experiences that can be emotional in nature, for example, the feel of a spider crawling on one's arm.

Active touch is more typical of much of our daily lives. We actively feel objects as we manipulate them, and one can consider perception as intimately linked to action from this perspective. In an active perceiver, touch is purposeful and can be involved in motor activity and perceptual functioning. These two basic life functions can be mixed in different proportions as we move about in the world, and people often overlook the important perceptual functions of touch. Thus, according to Gibson, active touch involves intentional movement where one tries to obtain useful perceptual information from or about an object, whether natural or artificial. We feel fruit to know if it is ripe and feel the grip of the automotive shift lever in a car to release the shift lever and change gears. Gibson thought that the active nature of touch has often been ignored in much of the more traditional research involving psychophysical methods.

The distinction between active and passive touch is not merely a dichotomy between the presence of kinesthesis and a lack of movement. Kinesthesis can involve active or passive movement. Intentional action is a critical aspect of active touch, according to Gibson.

The original experiments that purported to support the distinction between active and passive touch were flawed, but Gibson (1962) had an important point to make about the relevance of some of the work in the field. Gibson was concerned about whether or not we can generalize the results of data that derive from artificial and nonrepresentative methods to more normal, ecologically valid situations in the real world. Gibson pressed forms on the palms in his passive conditions and allowed for active exploration with the fingertips in active touch (haptics). The fingertips are certainly more sensitive than the palm, so there is a logical confound in the original experiments Gibson reported. Nonetheless, it has been shown that performance suffered when shapes were passively pressed on the fingers, compared with active exploration by the digits (Heller & Myers, 1983). Note that there are even difficulties with the study by Heller and Myers, since they compared the hairless, glabrous skin surfaces of multiple fingers in passive touch with the distal fingertips in active touch. Even here, the fingertips are more sensitive than areas of the fingers that are closer to the palm and wrist.

However, a considerable number of research publications have yielded somewhat divided results on this theoretical issue. While there is little doubt that there are many advantages to active touch and skilled exploration, there are demonstrations of the superiority of passive touch when feeling large raised patterns and movement control is a problem (Magee & Kennedy, 1980). Here, passive guidance of touch was better than active free exploration. There is also evidence that passive touch can prompt very high levels of recognition when one experiences letters, numbers, or other familiar patterns drawn on the skin of the palm (Heller, 1980, 1989b). People who are deaf-blind learn to use Print-On-Palm (POP) to communicate with sighted individuals who are unfamiliar with finger spelling or sign language. POP involves printing letters on the skin of the palm to produce words, and is a useful method of communication, even though it is passive.

It is clear that skill and practice are important factors here, since deaf-blind individuals can use passive touch to communicate by printing on the palm. Similar “passive stimulation” can occur with the Optacon, a reading machine for blind people. The Optacon converts visual spatial information about the configuration of letters or numbers into a pattern of pins vibrating against the stationary fingertip (Heller, Rogers, & Perry, 1990). It is normally used with a handheld camera to allow the conversion of visible print into the vibrotactile display. The camera is moved over a line of print while the index finger of the other hand feels the pattern on the vibrotactile display. There is evidence that active movement of the finger on the display will yield better pattern recognition using the Optacon, but passive touch on the Optacon display is the norm when the device is used by blind people. It would be nearly impossible to control camera scanning with one hand, while actively moving the index finger of the opposite hand on the vibrating pins. Bimanual movement control would be prohibitively difficult. Thus, blind people have learned to read visible print using the Optacon with passive touch for the finger on the vibrotactile display. Of course, one can argue that the perceiver is relatively active, since s/he controls the camera, and therefore the pattern of tactile stimulation. Moreover, blind readers of Braille can identify Braille when they are passively presented at very brief exposures (Foulke, 1982).

Ecological psychology has been transformed into a number of varying theoretical perspectives. For example, Gibson’s emphasis on the stimulus and the study of naturalistic circumstances has led to a large body of work on dynamic touch, involving people manipulating objects to gain information about their properties, such as their usefulness as tools (Michaels, Weier, & Harrison, 2007; Wagman & Carello, 2003). Ecological researchers are interested in the affordances of objects, that is, our knowing what can be done to them or with them. According to J. J. Gibson, "The affordances of objects are what it offers the animal, what it provides or furnishes, either for good or ill" (1979, p. 127). These affordances go beyond mere low-level stimulus properties, since they involve perceptual judgments about the functions of objects and their utility to us. The basic assumption is that object stimulus information constrains exploration and manipulation of the objects. This yields a constant and lawful relationship between the object and perceiver. The perceiver is presumably capable of extracting this complex information by way of object exploration. Thus, some objects are appropriate for hammering and others for poking (Wagman & Carello, 2003). Our manipulation of these objects and the available information about these objects will differ in terms of physical properties. The dynamic information that is available during object manipulation tells us about object properties.

Carello and Turvey (2000) assume that a major functional role of touch involves the control of action. On this view, dynamic touch entails registering resistance to rotational inertia and other object properties, since object movement requires this information. For example, when using a long cane or another tool, we can gain information about the external environment, or the object we are wielding.

J. J. Gibson (1979) argued that perceivers are tuned into stimuli, much as a radio can be tuned to a station. This tuning process ultimately derives from our evolutionary background and is modified by experience. People are fundamentally tool users, and this account seems to fit with everyday, commonsense thinking. The Gibsonian view is that we normally perceive the world accurately, and perceptual errors arise when stimulus information is sparse, viewing conditions are poor, or artificial and degraded stimuli are used in laboratory situations.

J. J. Gibson (1966) emphasized the multimodal nature of perception, that is, the idea that it is only in laboratories, and rarely in the real world, that we experience objects or surfaces through a single sense. As we touch objects, we can see the location of the objects and our hands or feet using peripheral, blurry vision (Heller, 1982, 1985b). We do not normally view objects without our bodies providing a frame of reference or context for visual information. The Gibsonian emphasis on multimodal perception has been echoed in a rapid growth in multimodal research that is relevant to touch. Thus, a large research literature has grown up devoted to multimodal research, involving multiple senses, with implications for neuroscience as well as human cognition (Spence & Driver, 2004). Of course, many current researchers in this area may not adopt a Gibsonian theoretical perspective, but some do. The important point is that multimodal research involving touch has increased in frequency with a variety of theoretical and practical viewpoints in evidence.

Illusions

Illusions are important for a number of theoretical reasons, and will be discussed at greater length in chapter 4 in this volume. On the realist, ecological perspective, one would expect that illusions derive from impoverished stimulation, poor or atypical conditions of observation, or stimuli that are artificial. There have been very few studies on precisely what a "natural" stimulus might consist of for haptics (but see Overleit & Soto-Faraco, 2011). On this theoretical perspective, line drawings are not like normal stimuli, since they do not contain planes and they are artificial constructions (Gibson, 1966, 1979). If illusions are not penetrable, and persist in naturalistic and optimal circumstances, then this is problematic for the ecological position, since it assumes that our perception of the world is generally veridical. Thus illusions are theoretically important.

Touch is susceptible to a number of the identical illusions that occur in vision, including the Müller-Lyer illusion, the horizontal-vertical illusion, and many others. One general issue is whether these illusions occur for the same reasons in both senses of touch and vision. It is very possible that different mechanisms are at work (Gentaz & Hatwell, 2004).

Developmental Issues, Aging, and Experience

There is evidence that there is a lag in the education and cognitive development of blind people (Hatwell, 1966/1985). It takes longer for blind individuals to complete school and one can see this revealed in cognitive differences when comparisons are made between sighted and blind people at an early age. Thus the educational experiences of blind persons are different than those of the sighted. It is problematic to know how much of the differences in the literature derive from a lack of education, or a lack of exposure to "visual" concepts in the blind. It bears repeating that there is a substantial lag in the perceptual and cognitive development of blind children, and this must be considered in evaluating the research literature (Hatwell, 1966/1985).

Developmental issues are important from a variety of theoretical perspectives. We are in a formative stage in discovering the potential of the sense of touch, and it may take some time for children to learn to coordinate the senses. An examination of haptic perception in the adult may miss many important problems, especially if those adults happen to be undergraduate student volunteers. The typical sighted person has far less experience with the use of touch perception for pattern identification or fine pattern discrimination. This has had implications for studies that have looked at aging and changes in sensitivity over time. For example, blind persons may not show comparable declines in tactile sensitivity that one finds with the sighted, when the relevant sensory surface is the tip of the index finger (Stevens, Foulke, & Patterson, 1996). One normally sees very large reductions in tactile sensitivity with age (Humes, Busey, Craig, & Kewley-Port, 2009).

The Impact of Neuroscience

There has been dramatic growth in neuroscience approaches to the study of touch. Many individuals believe that the methods of neuroscience will provide the highest quality of information about the operation of the sense of touch, and that cognitive sorts of approaches are "medieval." This view has often been related to the functioning of grant and funding agencies, and there is little doubt that a considerable body of new work has grown up in the field that adopts the methods of brain imaging or transcranial magnetic stimulation (TMS). TMS allows a researcher to temporarily "turn off" a section of the brain, and determine which cognitive or perceptual functions are affected (Pascual-Leone, Theoret, Merabet, Kauffman, & Schlaug, 2006). For example, research using brain imaging and TMS has shown that the reading of Braille is disrupted when the magnetic pulses affect the occipital cortex in congenitally blind individuals. However, the functioning of the occipital lobe was also altered by blindfolding sighted individuals for five days. Here, brain imaging showed that the occipital lobe was involved in processing Braille, unlike in the normally sighted who were only blindfolded for testing. Pascual-Leone and his colleagues (2006) have claimed that the cortex is subject to very rapid plasticity, even in adulthood. The basic idea is that brain tissue can take on new functions depending upon experience, and there is a great deal of evidence that the visual cortex is involved in the processing of information from the sense of touch.

There are significant practical and theoretical problems related to the use of the newest methods of neuroscience (Heller & Ballesteros, 2006). One sort of difficulty entails the necessity for very artificial circumstances such as immobilization, and it is not clear if the results of these studies using passive touch will generalize to more normal circumstances. Furthermore, the levels of analysis are different for studies involving cognitive and neuroscience approaches. It may not be a simple matter to reduce cognitive functioning in haptics to brain loci (Heller, 2000a).

New Technology, Sensory Aids, and Virtual Touch

The earliest attempts to develop sophisticated tactile devices to replace vision relied on vibrotactile arrays of stimulation to replace the eyes for people who are blind. Paul Bach-y-Rita and his colleagues were pioneers in the area, with the Tactile Vision Substitution System (TVSS), a low resolution vibrotactile array (Bach-y-Rita, 1972). The TVSS consisted of a large array of vibrating disks that were placed upon the back. A camera served to feed visual information to a computer that was used to drive the array. Using this device, blind individuals were able to "see" objects at a distance.

The basic idea of using vibrotactile arrays as a substitute for sight, later led to the later Optacon, a reading machine for blind individuals. The Optacon II was limited to a 5X20 array of pins that could be explored by the fingertip.

Recent technological advances have led to the development of very high density arrays, with 400 pins in a small, 1 cm^2 area (Killebrew et al., 2007). Some newer devices have relied on electrical arrays and have even involved placement on the tongue (Bach-y-Rita, Kaczmarek, Tyler, & Garcia-Lara, 1998). Researchers have experimented with placing arrays on a number of body locations. The selection of a body locus is always a compromise between allowing people the use of the extremities for mobility or object manipulation and the sensitivity of skin surfaces. Of course, affective consequences can play a role here, since many individuals may not be happy with electrical stimulation on any part of the body.

Recent technological advances have permitted the development of virtual touch devices. Early work in the area was pioneered by researchers at the Touch Laboratory at MIT. They developed an early form of the Phantom, a sophisticated and costly machine that has proven very useful for simulating touch sensations (Srinivasan & Basdogan, 1997). These force-feedback machines simulate the sorts of resistance one might experience when feeling surface textures, shapes, or the material properties of real objects. The devices have been used to augment remote sensing, as in robotic surgery.

In addition, force feedback devices have the potential to aid the training of surgeons to prepare them for surgery on real, rather than simulated people. It is no longer possible, for example, to train heart surgeons on live dogs, in the United States. They must take their preliminary surgical training using virtual reality. The sole use of visual virtual reality will not suffice to train an individual to use a scalpel, since one cannot "see" how much force is needed to part tissues with the blade. Virtual touch has a large number of potential applications in robotics, remote sensing, and medicine. Moreover, the use of virtual touch has other potential applications to a number of situations that involve human factors, including aeronautics, rehabilitation of blind or deaf individuals, and general education. The typical use of virtual touch is to augment vision, but other applications are possible in the complete absence of sight. This exciting new area will be discussed in more detail later in this volume.

2 Cognitive Neuroscience of Touch

The somaesthetic system is not a homogenous entity, for its sensory receptors are widely dispersed and have great functional diversity (Craig & Rollman, 1999; Kandel, Schwartz, & Jessel, 2000; Mountcastle, 1999). However, it is the common neural substrate for the two forms of manual tactile perception, cutaneous perception (or passive touch), and haptic perception (or active touch). According to J. J. Gibson (1962), being passively touched tends to focus the observer's attention on his or her subjective bodily sensations, whereas contact resulting from manual active exploration tends to guide the observer's attention to properties of the external environment.

Cutaneous perception and haptic perception can be also distinguished by the fact that in the latter, the motor system is involved in the exploratory activity of the hand that in turn can activate the whole shoulder-arm-hand system. In cutaneous perception, because the corporal segment stimulated is stationary, only the superficial layers of the skin undergo mechanical deformations and are therefore involved in perceptual processing. In haptic perception, the deformation of the muscles, joints, and tendons resulting from exploratory movements are combined with cutaneous perception. Haptic perceptual processing is therefore much more complex because it integrates cutaneous and proprioceptive cues. Because the exploratory movements are generally multi-articular, intentional, and self-initiated, they depend on neural circuits that are partly specific. Finally, because their speed is relatively slow, they may use sensory reafference produced by their execution. The goals of this chapter are to present some selected data, some general characteristics of anatomical factors, and a summary of the neurophysiological bases of cutaneous and haptic perception.

Many of the advances we have seen in our knowledge of the relationship between perceptual functioning and the brain emerged from new techniques and brain imaging. However, there have been some surprising and novel findings that have derived from the use of TMS, which allows the researcher to turn off parts of the cortex by pulsing the area with focused magnetic fields. This is a temporary and noninvasive method for evaluating cortical functioning. If a cognitive skill is lost when an area is turned off, the clear conclusion is that the cortical area is involved in processing. Of course, the entire story is more complicated than this, but the technique has certainly added to our knowledge of cortical functioning in intact normal individuals.

The Neural Bases of Touch

From Mechanoreceptors to Cortex

In cutaneous perception, information from the mechanical deformation of part of the skin is coded by cutaneous mechanoreceptors located within different layers of the hairless (glabrous) skin of the human hand. At least four types of receptors have been identified and include the Meissner's corpuscle, Pacinian corpuscle, Merkel disk, and Ruffini ending. They are classified on the basis of their adaptive properties. They could adapt rapidly and are active during the initial contact with the stimulus, or slowly and active during their entire contact with the stimulus. The characteristics of their receptive fields vary from small and highly localized or large, with indistinct borders (Johnson, 2001). Moreover, four thermal receptors modulate their firing as a function of temperature. They are very sensitive to differences between the temperature of the skin and the temperature of objects that are touched. Regarding pain, three classes of nociceptors can be distinguished on the basis of the type of stimulus. Thus, mechanical and thermal nociceptors are activated by particular forms of noxious stimuli, whereas polymodal nociceptors, the largest class, are sensitive to the destructive effects of a stimulus rather than to its physical properties.

In haptic perception, cutaneous information is joined by information from the mechanical deformation of the proprioceptive receptors, resulting from the exploratory movements of the shoulder-hand system. There are three types of mechanoreceptors that are situated in the muscles and include the muscle spindle receptors, tendons (the Golgi tendon organs), and the joints involving the joint capsule receptors. The muscle receptors mainly provide information on the length of the muscles or the speed of change in their length. The tendon receptors provide information on the level of tension of the muscle, the level of force developed, and its variation over time. The joint receptors allow us to sense flexion and extension of joints. These different receptors are involved in cutaneous and haptic perception, but each has specific roles depending on their properties (Table 2.1).

Moreover, in haptic perception, the peripheral sensory information described previously is not the only information available. Indeed, in the absence of peripheral sensory afference (deafferentation) and with an intact motor capacity, certain persons are capable of making fairly complex movements and seem to be informed about their performance. Also, amputees continue to feel the lost limb (Henderson & Smyth, 1948). This other information from the motor commands generating exploratory movements, called either corollary discharges (Sperry, 1950) or efference copies in the model described by von Holst