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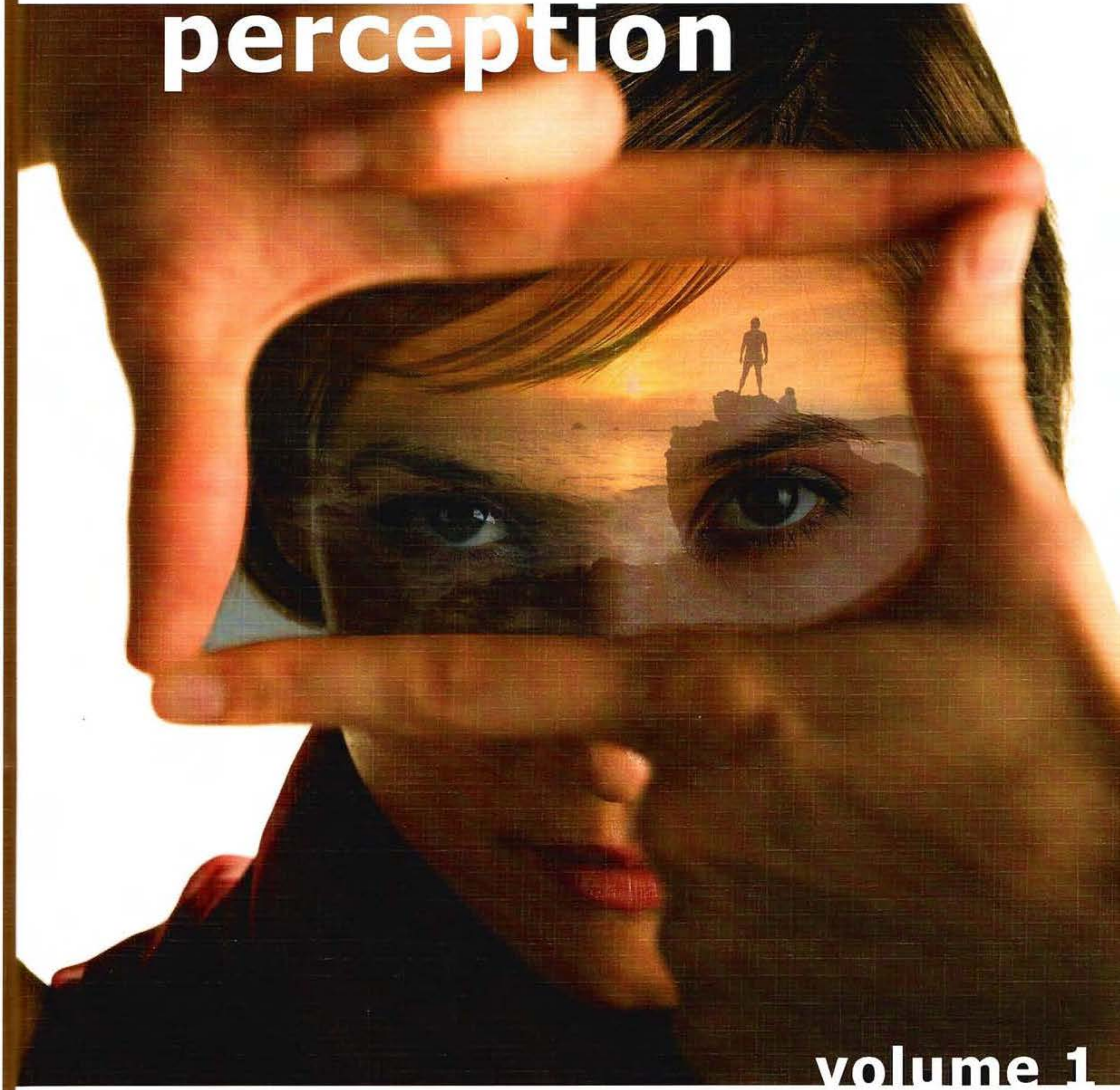
encyclopedia of perception



volume 1

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33 Pekin Street #02-01
Far East Square
Singapore 048763

Printed in the United States of America

Library of Congress Cataloging-in-Publication Data

Encyclopedia of perception/edited by E. Bruce Goldstein.
p. cm.
Includes bibliographical references and index.
ISBN 978-1-4129-4081-8 (cloth)
1. Perception—Encyclopedias. 2. Senses and sensation—Encyclopedias. I. Goldstein, E. Bruce, 1941–

BF311.E497 2010
153.703—dc22 2009010777

This book is printed on acid-free paper.

09 10 11 12 13 10 9 8 7 6 5 4 3 2 1

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personality psychology, as well as for cognitive psychology. The reasons are threefold. First, the cross-cultural examination of human perception allows us to examine in what ways, and to what extent, our perception is flexibly structured and influenced by systems associated with sociocultural experiences. Some researchers maintain that basic visual processing exists independently of socioculturally shared beliefs. Their findings suggest that the physical and structural systems of visual perception are sufficient for understanding human perception. However, under the rubric of "new look psychology," which emphasizes influences of beliefs and values on visual perception, researchers maintain that our perceptions, even perceptions of so-called neutral stimuli, are fully influenced by our knowledge structures, which in turn are based on our experiences. The underlying processes have not been fully investigated, however, and further research is necessary.

Second, social and cultural psychologists who have identified cultural variation in social cognition—such as causal attribution, self-perception, judgment, inference, and categorization—have long awaited more objective measurements than previously existing quasi-experimental and quasi-survey data collection, which was based mainly on participants' self-reports. Current technological advances allow cross-cultural researchers to scrutinize underlying processes of these variations in human behaviors.

Finally, the theoretical frameworks of perception research do not sufficiently account for the functions of emotions, motivation, and psychological states. Since the emergence of new look psychology, however, substantial numbers of studies have suggested that such factors play an important role in perceptual processes. Again, the findings of cultural influence on perception mutually accelerate further investigation into the complexity of human perception.

Takahiko Masuda

See also Aesthetic Appreciation of Pictures; Attention and Emotion; Color Perception; Eye Movements and Action in Everyday Life; Eye Movements During Cognition and Conversation; Individual Differences in Perception; Nonveridical Perception; Social Perception; Visual Illusions; Visual Scene Perception

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CUTANEOUS PERCEPTION

The skin, far from being just a passive wrapping for the body, provides a wealth of capabilities that combine to allow for extraordinarily complex patterns of perceptual experience. Although cutaneous perception might be taken for granted by most persons, for individuals with visual or auditory disabilities, their impression of the world can depend heavily on their senses of touch. Cutaneous perception results from combinations of responses from skin receptors, evoked by mechanical and thermal stimuli, and, occasionally, chemical and painful events. Historically, there has been some question about the structures and mechanisms that mediate these percepts, partially because it is so difficult to isolate the suspect components, and because some sites (such as the cornea of the eye) are sensitive to touch, temperature, and pain, yet do not possess specialized structures. Nevertheless, converging data from anatomy, physiology, and experiments using "psychological dissection" have led to strong contemporary models of underlying structural-functional relationships.

Mechanical stimuli include static pressure, movement—such as stroking and vibration—and even skin stretch. Thermal stimuli can result from warming or cooling shifts in skin temperature, with extremes that produce pain. Even chemical stimuli, such as pain-relieving salves, generate numerous sensations, including cooling from menthol and heating and irritation from capsaicin. And electricity, the great nonspecific stimulus, can evoke similar perceptual experiences, bypassing receptors to activate nerve fibers directly, mimicking sensations produced by normal ("adequate") stimulation of the skin. To complicate matters further, these qualities can combine to evoke complex illusory percepts—for example, cold pressure stimuli can feel wet (like touching mercury), and the perception of movement can be produced by a rapid sequence of touches.

Cutaneous perception can result from passive contact with static or moving point-like ("punctate") stimuli, such as a mosquito lighting on our arms, or extended 2-dimensional surfaces, such as sandpaper, the tines of a comb, or even dense vibrotactile displays like the Optacon, a machine that blind people use to read print. Similarly, we are sensitive to changing stimuli, such as the warming of a coffee cup, and are aware, through the whole body's surface, when the ambient room temperature drops several degrees. More complex percepts can be evoked from active exploration of simple or multidimensional stimuli, as when we try to identify a Braille character, determine a tomato's ripeness, or assemble a wristwatch. Sensitivities to stimuli vary across the body, leading to different perceived qualities. This situation holds because the structures that subserve tactile experience, the cutaneous receptors, differ in type and density from one site to another. For example, the elbow has recently been empirically shown to be a more sensitive site for thermal stimuli (as mothers, testing their babies' bathwater, have always known) than other areas of the arm.

The skin has two broad divisions—glabrous (smooth) skin, such as the fingertips, and hairy skin, which covers most of the human body. Distinctions between these two skin types include the presence or absence of hairs and the intricate labyrinthine fingerprints. Most research studies of the skin and its capabilities have concentrated on glabrous sites, particularly the fingers and hands. From these experiments, physiological models of cutaneous perception that relate particular characteristics of tactile experience, such as roughness or stretch, have been proposed (Joel Greenspan and Sandy Bolanowski provide a detailed history and description). Because of differences in the receptor populations between the skin types, these models based on glabrous skin should be extrapolated to areas such as the limbs or trunk, only with great caution. This entry discusses cutaneous perception in relation to intensity, space, and time and describes real and virtual tactile surfaces and environments.

Cutaneous Perception and Intensity

Research has shown that tactile perception of simple points, or "asperities," can be extraordinarily acute—we can feel (and localize) 1 micrometer "bumps" on an otherwise smooth surface with our fingertips. Our experience of feeling imperfections along the surface of an automobile or piece of furniture attests to this ability. Place that bump into motion by vibrating it, and our sensitivity can improve a great deal, under certain conditions. Vibrating an area on the fingertip the size of a pencil eraser at a frequency of about 250 hertz (Hz) can be felt at signal amplitudes of much less than a micrometer. The fingertips, sometimes characterized as the "retina" of the skin, are the most sensitive to vibration. Move that stimulator to the palm of the hand, the wrist, forearm, or chest, and sensitivity drops by a factor of as much as 100. One of the underlying mechanisms for this sensitivity gradient is the reduction in the number of receptors and changes in receptor types. For example, Roland Johansson and Åke Vallbo report that there are more than 130 Meissner's corpuscles per square centimeter (cm^2) in the skin of the index fingertip, whereas at the base of the thumb, there are fewer than 30/cm^2, and they don't seem to exist at all in hairy skin.

The maximum intensity that can be felt depends on a number of stimulus conditions, including site, frequency, contactor size, and age. Usually pain or tissue damage defines the upper limit, but a usable dynamic range between just noticing a stimulus and a comfortably "loud" level can be as much as 10,000:1. Despite this large range, if we wanted to use tactile signals—say, in a cardiac emergency code indicating a range of importance from "Check your blood pressure" to "Call 911!"—cognitive limitations restrict the number of useful intensity levels to three or four, even though we can discriminate many more differences when directly compared. Roger Cholewiak consulted on this kind of problem in the development of an implanted cardiac monitor, the AngelMed Guardian, in which subcutaneous tactile feedback is used to warn the user of the severity of an identified condition. Finally, Joseph Stevens and his colleagues have quantified changes over body loci that occur with aging. These are generally attributed to the reduction in number and "health" of the most sensitive touch structures in elderly persons.

Cutaneous Perception and Space

Of the spatial modalities, touch falls between vision and audition in its acuity, being less precise than vision but more precise than hearing. It is not difficult to locate an insect on the arm because it bends hairs while it walks about. Generally, the ability to localize vibrations on the 2 square meters (m^2) of the skin can be quite good, as long as they can be felt. This ability has been tested empirically with both active and passive presentations of stimuli. Active exploration mimics the typical way we use our skin in everyday life ("haptics"). Passive stimulus presentations, however, allow the researcher to control the signal more precisely, but at the expense of losing the richness of kinesthetic and motor feedback that enhances "everyday" spatial percepts. In the same way that sensitivity to a stimulus varies over the body, so does our ability to localize an event: Touch the fingertip lightly with a pencil point and it will be felt every time; on the back of the hand it will be felt often, but not always, whereas on the chest a light touch might be missed at many loci. A sidelight of this demonstration is to attend to the "coolness" of the tip. On the back of the hand most touched points will be felt as neutral, but occasionally, "cold spots" will brightly announce their presence. These demonstrate that the distribution of cutaneous receptors is neither dense nor uniform. There is an interaction between this punctate sensitivity and perceived intensity: The skin's sensitivity to warmth (as well as to higher-frequency vibrations) depends on the area of stimulation. Specifically, the larger the region warmed or the size of the contactor, the "louder" the sensation, a characteristic called *spatial summation.*

The ability to distinguish whether one or two points have been touched depends on how far apart they are, increasing from about a millimeter on the fingertip to several centimeters on less-sensitive areas such as the abdomen or thigh. Interestingly, there are certain "anchor points" near which localization is better. Although the limb joints serve this function, the midline of the body—front and back of the trunk—have recently been shown by Roger Cholewiak and his colleagues to anchor near-precise localizations. Finally, as Stevens and his colleagues have shown, spatial acuity deteriorates with age, as do many perceptual functions.

A one-dimensional stimulus such as a vibrating point might be employed for a kind of tactile Morse code, or to signal the presence of an event, but the temporal characteristics of the skin limit transmission rates for complex streams. More useful information can be communicated to a person with two-dimensional displays, such as Braille cells, incorporating spatial information. Experienced Braille readers can read at 60 words per minute (wpm), although 300 wpm rates have been reported. (Visual rates range from 250 to 400–600 wpm.) What limits the processing of tactile patterns? One important factor is *masking,* in which stimuli preceding or following a pattern degrade its processing. This degradation can take the form of changes in sensitivity, or in the ability to recognize the pattern. In the latter case, depending on the relative shapes and the timing between patterns, features can be dropped, added, or distorted. For example, a "P" might be perceived as an "F," or an "H" felt as an "A," as James Craig's extensive work has shown. These interactions typically occur when presentations occur within 200 milliseconds (ms) of one another, regardless of whether they are static or scanned across the finger. Another type of spatial interaction, reviewed by Lynette Jones and Susan Lederman, is related to patterns "drawn" on the skin's surface (*graphesthesia*), and the position of the body part in space. Here, identification of similarly shaped letters (such as b, d, p, q) drawn on the hand, arm, thigh, or forehead can depend on the limb's orientation and "point of view" (egocentric vs. allocentric) taken by the viewer. These data suggest that mobile body sites should be used for tactile displays only with caution. The torso has been chosen to present tactile information about the environment for navigation in cases of sensory disability, or for displays for situation awareness (such as Angus Rupert's aircraft Tactile Situation Awareness System) to augment overloaded "major" senses.

Cutaneous Perception and Time

Regarding temporal acuity, the skin again takes the middle ground, this time being more acute than vision but less acute than audition. Tests of temporal order indicate that there is some parity among these modalities (the chemical senses usually being considered far slower), so that regardless of the stimulus, a separation of about 20 ms is required to identify the order of two events (brief clicks, flashes of light, or taps on the skin). We are also able to detect gaps in prolonged single-frequency vibration or vibrotactile "noise" (where many frequencies are combined), but again, depending on a number of factors, such as age and stimulus intensity, gaps shorter than 250 ms are difficult for observers to appreciate.

Like vision and audition, tactile perception is limited to a narrow range of temporal variation (frequencies). Whereas the other mechanical sense, audition, has a useful frequency range from 20 Hz to about 20 kilohertz (KHz), that of the skin is more limited, from about 20 to 300 Hz. There are instances of low frequency sensitivity, say to swaying of a tall building, but those experiences are often ephemeral and the sensations confused with internal body functions. And, like vision and audition, a tactile stimulus has to stay on for some minimal time before the richness of its qualities can emerge. A pressure pulse (a "touch") can be felt if it is as brief as 2 ms, and increases in perceived intensity with duration, a phenomenon described as *temporal summation.* But not only do stimuli briefer than about 200 ms have to be presented at higher intensities even to be felt, for durations far below than this, vibration will not feel periodic (nor will sound have tonal quality—the "atonal" interval). However, because the more-sensitive skin receptors tend to respond best to transients, even more durative stimuli (either pressure or vibration) won't necessarily be appreciated as being proportionally stronger and might lead to the sensory phenomenon known as adaptation. That is, like the constant pressure of the clothes on our body, prolonged vibration leads to a reduction in apparent intensity.

So, the changes in the several perceptual qualities associated with temporal summation lead to a recommended upper limit for vibrotactile bursts of about 200 ms, beyond which sensation magnitude can fall. There is a similar range of thermal sensitivity (our "physiological zero") that occurs over a limited span of ambient temperatures where we may feel neither warm nor cool, given enough time to adapt. All our sensory systems are tuned to respond to changes, considering constant stimuli less informative: Sitting still provides little information about our clothes, but move the arm and we can become aware of the fabric around our sleeve, if we pay attention. Given these limitations, a vibrotactile Morse code could result in communication with relatively slow transmission rates (Hong Tan and Nat Durlach showed that at most, about 20 wpm can be achieved tactually, the amateur level for acoustic Morse).

Interestingly, when trying to determine whether one or two points have touched the skin, introducing a difference in time can make the task trivial. Even when identifying the orientation of two-dimensional gratings (similar to the tines on a comb), if the fingertip can stroke the surface rather than have it passively touched, the array becomes a spatiotemporal display and the groove orientation becomes immediately obvious. Research has shown that grid orientation tasks clearly show the influences of aging on the ability to distinguish texture, as long as stimuli are passively presented. However, allow the finger to stroke the surface and there is no difference between a 10-year-old and an octogenarian.

Because movement is a change in location over time (spatiotemporal), it has a number of perceptible qualities in those domains, such as direction, distance, and velocity. Greg Essick has shown that movement can be generated on the skin in a variety of ways (such as a brush dragged across the skin or a series of taps on individual vibrators), and that we are good at identifying its direction, unless the movement is very fast. Our perception of extent and "straightness" also depend on velocity: If the sequence is too fast, perceived extent may be foreshortened, but if it is too slow, the path may wander. With appropriate controls, illusory motion (akin to vision's "Phi") can be observed with only two tactile stimuli, such as vibrations at locations separated by 10 cm and 100 ms. A different illusory experience, described by Frank Geldard, is evoked by a sequence of, say, five taps at one site, followed by a sixth at a second site about 10 centimeters (cm) away, with inter-tap intervals of about 50 ms. In this case (sensory saltation), the series will be felt evenly distributed between the two sites. In all of these, the sensations of movement can generate tactile "vectors" within virtual environments for communication systems and appear to have correlates in the central nervous system.

Tactile Surfaces and Environments: Real and Virtual

Because of the interest in applying tactile displays to enhance virtual environments, as well as for sensory substitution and augmentation, it has become important to study the ability of the skin to appreciate physical dimensions of real-world surfaces and structures. As children, we would lay paper on the ground and create patterns with crayons, the tip rising and falling with the underlying surface. This texture was transmitted to cutaneous receptors via the crayon's vibration, and the surface roughness perceived through two primary sources. The vibrotactile information, spatial variation over time, conveys something about a surface's features, but alone does not provide enough information to form the percept of a texture (e.g., a vibrating cell phone does not feel like sandpaper). Adding proprioceptive feedback—information from muscles and joints—gives egocentric knowledge of the relative locations of each body part. The combined information from vibrotactile and proprioceptive sources underlies tactile perception of texture. Additional information, such as from vision, can form an even stronger percept.

Combinations of these spatial and temporal qualities in tactile exploration can make us aware of a number of physical surface qualities, including stiffness, force, and friction. To assess the ripeness of a pear, it's often helpful to squeeze the fruit and feel its stiffness. Stiffness—the force exerted by a surface proportional to the distance it is compressed or stretched—can be perceived because of the mechanical stimuli (static pressure and movement) and the proprioceptive feedback of the joints. Force is a bit more difficult to distinguish from other characteristics because the static pressure sensed by the cutaneous receptors is supplemented by skin stretch and displacement. Some attributes of a surface, such as friction, might be appreciated using vision, but the skin often provides information that would be otherwise imperceptible, such as the stickiness of flypaper. Although vision helps to guide the extremities, haptic information ultimately provides information about the complex forces (e.g., weight and friction) and compliancy of surfaces, as Steven Cholewiak, Hong Tan, and David Ebert have shown. These qualities, as well as texture, are important for appreciating surfaces in everyday and virtual realities.

There is particular interest in using cutaneous perception and haptics to enhance skill learning in many virtual environments such as telesurgery. Telesurgery, performed using a human-controlled robot, relies on surgeons' abilities to map their movements with controllers to the three-dimensional locations of the robot's appendages. It requires long and tedious practice proficiency. Any features that could make the surgery more "life-like" can potentially smooth the transition. By providing haptic force and cutaneous feedback (e.g., texture, pressure, temperature, stiffness), learning time may be reduced and the procedure taught to a wider array of individuals, who may have avoided the technology because of its perceptual sterility.

Roger W. Cholewiak and Steven A. Cholewiak

See also Cutaneous Perception: Physiology; Haptics; Texture Perception: Tactile; Vibratory Perception; Virtual Reality: Touch/Haptics

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CUTANEOUS PERCEPTION: PHYSIOLOGY

A major challenge in neurobiology is to understand how the brain constructs mental images of the world around us. The mental images that arise from the sense of touch are based on continuously changing patterns of electrical activity called action potentials that are evoked in the nerves that innervate the skin, muscles, and joints. The dynamic patterns of action potentials that come from the skin are the basis of cutaneous perception. These patterns are sent to the central nervous system via two main nuclei located in the brain stem and thalamus. Once the information reaches the cortex, it is systematically transformed through several processing stages into an alternate transformed pattern that is matched against previously stored patterns to evoke mental images of objects and surfaces in contact with the skin. The challenge facing neurobiologists is to understand the anatomical pathways and neural circuits that transform the patterns from the initial pattern into the representation that underlies memory, in other words, the challenge is to understand the neural code(s) that underlie behavior.

When exploring and manipulating an object with our hands, we readily appreciate many qualities or features of the object. These features include characteristics such as its size and shape, the texture of the surface, its weight, and dynamic properties, such as whether it is stationary or is moving in our hand. Many studies have shown that our ability to discriminate and identify objects is based on a rapid pattern recognition mechanism. For example, common everyday objects are recognized (typically in less than 3 seconds) without visual input at accuracy rates greater than 96%. In those experiments, subjects typically report that they identified the object using two to three features, such as its size and texture. In addition to be being highly accurate and rapid, the cutaneous system is also extremely sensitive with young adults being capable of detecting vibrations with amplitudes as low as 100 angstroms.

Discovering the neural code(s) that underlie cutaneous perception has been difficult for a number of reasons. First, the sense of touch is composed of multiple sub-modalities with individual

encyclopedia of **perception**

The field of perception is devoted to explaining the operation of the senses and the experiences and behaviors resulting from stimulation of the senses. Perceptual processes such as recognizing faces, seeing color, hearing music, and feeling pain represent the actions of complex mechanisms, yet we usually do them easily. The **Encyclopedia of Perception** presents a comprehensive overview of the field of perception through authoritative essays written by leading researchers and theoreticians in psychology, the cognitive sciences, neuroscience, and medical disciplines. It presents two parallel and interacting approaches: the psychophysical, or determining the relationship between stimuli in the environment and perception, and the physiological, or locating the biological systems responsible for perception. Are there any processes not associated with perception? Surely there are, but the pervasiveness of perception is truly impressive, and the phenomena of perception and its mechanisms are what this encyclopedia is about.

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key themes

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ISBN 978-1-4129-4081-8

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