What Is Touch? How Brains Make Touch and Temperature Sensations

Contents

Abstract

Brain transforms perceptual properties into patterns and motions of geometric-algebra vectors, making microscopic surface textures whose spatial and temporal properties are sensory experiences.

Keywords

A-beta fiber, brainstem nuclei, cerebellum, cuneate nuclei, dorsal root, egocenter, encapsulated mechanoreceptor, epicritic pathway, fast-adapting fiber I, fast-adapting fiber II, free nerve ending, gracile nuclei, hair cell, hair follicle nerve, haptic perception, haptic touch, Iggo-Pinkus dome, Krause's end bulb, lateral cervical nucleus, lemniscal system, mechanoreceptor, Meissner corpuscle, Merkel-cell neurite complex, ODC enzyme, pacinian corpuscle, palisade cell, parietal lobe, proprioception, Ruffini ending, Ruffini's endorgan, slow-adapting fiber I, slow-adapting fiber II, spinal cord, stereocilia, tactile receptor, thalamus, thermoreceptor, what system, where system

1. Anatomy

Skin mechanical receptors send to spinal cord, brainstem nuclei, thalamus, and parietal lobe.

1.1. Mechanical receptors

Skin, muscles, tendons, joints, alimentary canal, and bladder have mechanical receptors that detect tissue strains, pressures/stresses (compression, tension, and torsion), motions, and vibrations. Eight basic mechanoreceptor types each have many variations, making thousands of combinations.

Skin has encapsulated mechanoreceptors {tactile receptor}. Skin mechanoreceptor fibers {A-beta fiber} can be large.

Skin has specialized free nerve ending mechanoreceptors.

Skin hair-cell mechanoreceptors have tip cilia {stereocilia}. Hair cells send to brainstem and receive from brain.

Primate glabrous-skin encapsulated mechanoreceptors {Meissner corpuscle} {fast-adapting fiber I} are fast-adapting, have small receptive fields of 100 to 300 micrometers diameter, and lie in rows just below fingertip surface-ridge dermal papillae. Meissner's corpuscles send to myelinated dorsal-root neuron fibers. In mammals other than primates, skin encapsulated mechanoreceptors {Krause's end bulb} are mostly in genitals, tongue, and lips.

Numerous encapsulated mechanoreceptors {Merkel-cell neurite complex} {slow-adapting fiber I} form domes {Iggo-Pinkus dome} visible at skin surfaces. Merkel cells are slow-adapting, have small receptive fields of 100 to 300 micrometers diameter, and are in hairy-skin epidermis-bottom small, scattered clusters and in glabrous-skin epidermis rete pegs. Merkel cells send to myelinated dorsal-root neuron fibers.

Encapsulated mechanoreceptors {pacinian corpuscle} {fast-adapting fiber II}, 1 to 2 mm diameter, are fast-adapting, have large receptive fields, and are in body, joint, genital, and mammary-gland hairy-skin and glabrous-skin deep layers. Pacinian corpuscles have lamellae. Pacinian corpuscles send to myelinated dorsal-root neuron fibers.

Hair follicles have pressure mechanoreceptors {hair follicle nerve} {palisade cell}, around hair-shaft base, that have three myelinated-fiber types.

Encapsulated skin mechanoreceptors {Ruffini's endorgan} {Ruffini ending} {slow-adapting fiber II} are spindle shaped and 1 mm to 2 mm long, similar to Golgi tendon organs. Ruffini's endorgans are slow-adapting, are in joints and glabrous-skin dermis, and have large receptive fields, several centimeters diameter in arms and trunk. Ruffini endorgans have densely-branched center nerve endings. Ruffini endorgans send to myelinated dorsal-root neuron fibers.

Skin mechanoreceptors {thermoreceptor} can detect surface temperature. Muscles, tendons, joints, alimentary canal, and bladder have thermoreceptors. Skin mechanoreceptors {cold fiber} can detect decreased skin temperature. Cold receptors are mostly on face and genitals. Skin has receptors {warmth fiber} that detect increased skin temperature. Heat receptors are deep in skin, especially in tongue. Warm fibers are 30 times fewer than cool fibers.

1.2. Brain

Myelinated-fiber pathways {epicritic pathway} {lemniscal system} begin at Meissner's corpuscles, Pacinian corpuscles, hair root structures, muscle spindles, or Golgi tendon organs, go to spinal-cord dorsal root, go through lateral cervical nucleus, continue to gracile and cuneate nuclei, and end at cerebellum and thalamus.

Forebrain parietal lobe is for touch and temperature.

2. Physiology

Mechanoreceptors detect pressures/stresses (compression, tension, torsion), strains, motions, and vibrations [Bolanowski et al., 1998] [Hollins, 2002] [Johnson, 2002]:

- Free nerve ending: smooth or rough surface texture
- Hair cell: motion
- Meissner corpuscle: vibration
- Merkel cell: light compression and vibration
- Pacinian corpuscle: deep compression and vibration
- Palisade cell: light compression
- Ruffini endorgan: slip, stretch, and vibration

Enzymes {ODC enzyme} begin touch chemical changes.

Touch stimuli affect many touch-receptor types, which excite and inhibit each other to form intensity ratios. Receptors do not make equal contributions but have weights. Receptor sensitivity varies over touch spectrum and touch region [Katz, 1925] [McComas and Cupido, 1999] [Teuber, 1960].

2.1. Pressure

Skin encapsulated tactile receptors are for steady pressure and light touch.

Skin free-nerve-ending mechanoreceptors respond to all skin-stimulation types.

Merkel cells detect continuous pressures and deformations as small as one micrometer.

Pacinian corpuscles detect deep pressure.

Palisade cells respond to different deformations.

Ruffini endorgans respond to skin slip, stretch, and deformation, with sensitivity less than that of slow-adapting fiber I receptors.

Nerve signals differ for pain, itch, heat, and pressure [Bialek et al., 1991]. Pressure has high intensity that fades away. (Pain is irregular and high intensity and has rapid increase. Itch is regular and fast. Heat rises higher.)

2.2. Vibration

Skin encapsulated tactile receptors are for vibration.

Skin free-nerve-ending mechanoreceptors respond to all skin-stimulation types.

Meissner's corpuscles respond to vibration, to detect changing stimuli. Maximum sensitivity is at 20 to 40 Hz. Range is from 1 Hz to 400 Hz.

Pacinian corpuscles respond to vibration with maximum sensitivity at 200 to 300 Hz. Range is 20 to 1500 Hz. Pacinian corpuscles can detect movements smaller than one micrometer. Pacinian-corpuscle lamellae act as high-pass filters to prevent steadily maintained pressure from making signals.

Palisade cells respond to vibration frequencies from 1 to 1500 Hz.

Ruffini endorgans respond to 100 Hz to 500 Hz.

2.3. Movement

Skin hair-cell mechanoreceptors detect movement.

Skin free-nerve-ending mechanoreceptors respond to all skin-stimulation types.

Touch can tell whether a surface is sliding under stationary skin, or skin is sliding over stationary surface. Objects that slide past stationary skin have inertia similar to or less than the body. The touch system measures accelerations and decelerations in the skin. Large decelerations in skin result from sliding skin by stationary objects. Small decelerations in skin result from objects sliding by skin.

During body movements, neuron activations follow trajectories across topographic maps. Brain can track moving stimuli.

2.4. Material properties

Touch can identify {what system}. Skin, muscles, tendons, and joints have mechanoreceptors that work with muscle movements to explore environment. When touching objects, people use hand-movement patterns {exploratory procedure} to learn about features {haptic touch} {haptic perception}. Touching by active exploration with fingers uses one information channel. (Passive touch uses parallel channels.)

Holding in hand determines weight.

Touching with no moving determines temperature. Material properties determine heat flow, which determines temperature.

Applying pressure determines hardness.

Sliding touch back and forth determines texture.

Wrapping around determines shape and volume. Following contours determines shape.

Touch is more about weight, heat transfer, texture, and hardness than about shape. Weight discrimination is best if lifted-weight density is one gram per cubic centimeter.

2.5. Temperature

Coolness and warmth are relative and depend on body-tissue relative average random molecule speed. Very cold objects can feel hot at first. Skin is normally 30 C to 36 C. If objects are colder than 30 C, cold fibers provide information about material as heat flows from skin to object. If skin is above normal temperature, warmth fibers provide information about material as heat flows from skin to object. Warmth fibers also provide information about body state, such as fever or warm-weather overheating.

3. Perceptual properties

Touch perceptual processes [Bolanowski et al., 1998] [Hollins, 2002] [Johnson, 2002] compare free nerve ending (smooth or rough surface texture), hair cell (motion), Meissner corpuscle (vibration), Merkel cell (light compression and vibration), pacinian corpuscle (deep compression and vibration), palisade cell (light compression), and Ruffini endorgan (slip, stretch, and vibration) inputs to find compression-tension, vibration, and motion. People can distinguish one million different touches.

3.1. Strength

Strength relates to pressure/stress. Strong touches have high pressure. Weak touches have low pressure. People can distinguish 10 compression-tension levels.

3.2. Sharpness-smoothness

Area relates to number of receptors. Sharp pressure typically has small area and high pressure. Smooth touches relate to large area and low pressure. People can distinguish 10 sharpness levels.

3.3. Steadiness-vibration

Vibration makes pressure alternate off and on at a receptor. People can feel vibrations up to 20 Hz. Tickle, tingle, and "butterflies" have vibrations. People can distinguish 10 vibration levels.

Steady touches have no vibration. Gentle touch and sharp pressure are steady.

3.4. Motion

Motion relates to changing pressures at a series of receptors. People can distinguish 10 motion speeds.

3.5. Temperature

Cool temperatures relate to slow heat flow. Warm temperatures relate to fast heat flow.

Temperature perceptual processes compare thermoreceptor inputs. Temperature relates to relative heat flow. Heat flow determines temperature. People can distinguish 10 temperature levels.

3.6. Mixing

Touches can mix, so touch is a synthetic sense, with some analysis.

Touches do not have opposites.

3.7. Source location

Touch can locate body and objects {where system}.

From one location, touch detects only one source.

Touch can detect multiple sensations simultaneously.

Touch has no fixed coordinate origin (egocenter), so coordinates change with task.

3.7.1. Space

Skin touches objects, so touch receptors receive information about objects adjacent to body. As body moves around in space, mental space expands by adding adjacency information. From receptor activity patterns, nervous system builds a three-dimensional sensory surface.

Foot motions stop at ground. Touch and kinesthetic receptors define a horizontal plane in space.

People can distinguish inside-body stimuli, as self. Tightening muscles actively compresses, to affect proprioception receptors that define body points. When people move, other objects do not move, so correlated body movements belong to self.

People can distinguish outside-body stimuli, as non-self. During movements or under pressure, body surfaces passively extend, to affect touch receptors that define external-space points. When people move, correlated non-movements belong to non-self.

Because distance equals rate times time, motion provides information about distances. Nervous system correlates body motions and touch and kinesthetic receptors to extract reference points and three-dimensional space. Repeated body movements define perception metrics. Such ratios build standard length, angle, time, and mass units that model physical-space lengths, angles, times, and masses. As body, head, and eyes move, they trace geometric structures and motions.

4. Relations to other senses

Hearing, temperature, and touch involve mechanical energy.

Touch can feel vibrations below 20 Hz. Sound vibrates eardrum and other body surfaces but is not felt as touch.

Touch locates smells in upper nose.

Touch locates tastes on tongue.

Touch coordinates with vision.

Nociceptive and thermal receptor systems interact. Tactile and thermal receptor systems interact.

Temperatures relate to colors because warm colors expand and cool colors contract.

5. Touch sensations

Touch detects surface pressure, compression, stretch, slip, texture, vibration, motion, and temperature.

Pressure and touch receptor activity increases muscle flexor activity and decreases muscle extensor activity.

6. Touch descriptors

Touch perceives surface temperature, surface curvature and shape (pointed or rounded), surface elasticity, surface texture (roughness or smoothness), object (gas, liquid, solid) density, object hardness-softness, object weight, object vibration, object motion, body motion, body compression, body tension, and body torsion.

Touches have pressures, and so force and area. Touches have inelastic stresses.

Touches can feel like pressures and like resistances. Touches can feel soft or hard.

Touches have surface curvatures and contours. Touches can feel sharp or smooth.

Touches can feel like tickles, tingles, or "butterflies".

Temperatures are kinds of pressures. Temperatures feel cool, neutral, or warm. Temperatures feel like inflows or outflows.

7. Spatiotemporal properties and patterns

Touch and temperature perceptual-property spatiotemporal patterns are surface-area radial motions.

Touch sensations feel like surface-area curvings.

8. Machines

Machines can simulate temperature sensations using a microscopic-surface-texture array with elements that move at a rate directly proportional to stimulus-surface temperature. More elements represent higher temperature.

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Note: The Bibliography of Touch and Tactile and the Consciousness Bibliography of 10,000 books and articles, with full journal and author names, is available in text and PDF file formats at http://www.outline-of-knowledge.info/Consciousness_Bibliography/index.html.

Date: February 27, 2016