The tactile senses & haptic perception

Jussi Rantala
Tampere Unit for Computer-Human Interaction (TAUCHI)
School of Information Sciences
University of Tampere, Finland

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1. The sense of touch
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• Touch is our oldest, most primitive and pervasive sense
  - The first sense to develop and respond to stimulation in uterus (during 8 to 14 weeks of gestation)

• Touch is important in several domains of life across the life span, particularly in early life
  - Touch helps us learn about the world around us
  - Plays an integral role in biological, cognitive, and social development
The sense of touch 2/3

- Touch is a proximal sense, i.e., we feel things close to us or in contact with us
  - Some exceptions occur, e.g., heat radiation & deep bass tones
  - We can also touch remotely with special tools (e.g., a white cane provides vibratory and pressure information for a blind)

- The sense of touch covers all major parts of our body
  - Compared to other senses, many things related to touch remains unknown
The sense(s) of touch 3/3

- Touch is often considered one of the five human senses defined by Aristotle
  - However, when a person touches various feelings from pressure to temperature and pain are evoked

- Thus the term “touch” is actually a combined term for several sub-modalities
  - In the field of medicine the term touch is usually replaced with the term somatic senses to better reflect the variety of sensory mechanisms involved

- The senses of touch are mediated by the somatosensory system
”The little man inside the brain”

- Sensory homunculus for touch
  - Visualizes the proportional sensory perception mapping of the body surfaces in the brain
  - Lips, tongue, hands, feet and genitals are considerably more sensitive than other parts of the body

Natural History Museum, London
http://www.nhm.ac.uk/
Somatosensory system 1/2

• A sensory system associated with the body

• Concerned with sensory information from the skin, joints, muscles and internal organs
  - The sensory information is highly sensitive to temperature

• Three main modalities:
  - Discriminative touch
  - Temperature & pain
  - The kinesthetic senses

  \[ \text{Tactile/cutaneous} \quad (\text{this lecture}) \]

  \[ \text{Proprioception} \quad (\text{mainly lecture 5}) \]
Somatosensory system 2/2

• Each somatosensory modality has its own receptors or nerve endings

• Basic function of somatosensory pathway in short:
  1) If a stimulus is larger than the threshold of the receptor, a response is triggered
  2) Electrical discharge is carried by the afferents to the peripheral nerves
  3) Impulses travel through spinal cord to the brain
  4) The sensations are registered at the somatosensory cortex in the brain
     - The greater the stimulus the more the receptor discharges & the larger amount of receptors discharge
Receptor classifications 1/2

• Location based classification
  - *Skin receptors* (exteroceptors) are located close to the skin surface (e.g., touch-pressure, vibration, temperature, pain)
  - *Muscle and joint receptors* (proprioceptors) are located in tendons, muscles and joints (e.g., position & movement)
  - *Visceral receptors* (interoceptors) are associated with the internal organs (e.g., heart rate, blood pressure)
• Transduction mechanism based classification
  - *Mechanoreceptors* are responsive to any kind of mechanical skin deformation
  - *Thermoreceptors* are responsive to changes in skin temperature
  - *Chemoreceptors* are responsive to substances produced within the skin
  - *Nociceptors* are specialized for detecting painful stimuli
The tactile senses
Tactile sensing

- Tactile sensations are experienced with the entire skin surface
  - Different areas of skin have different qualities (e.g., hairy skin has a “soft touch” channel that is found to be associated with emotions)

- Tactile sensing plays an important role in object discrimination and manipulation
  - Contact detection (pressure)
  - Surface texture (vibration & skin deformation)
  - Tool manipulation (pressure, vibration & skin deformation)
Skin 1/2

- The largest & heaviest organ in human body (~1,8 m², 4 kg)
  - Viscoelastic tissue (stretches & maintains its shape)
  - Protects the body from dehydration & physical injury
  - Regulates body temperature & blood pressure
  - Contains structures responsible for ability to feel

- When we feel embarrassed, touched, self-conscious, or angry we can often feel it directly as a charge at skin level
  - For example, blushing and turning red when giving a talk
Skin 2/2

- **Layers of the skin**
  - *Epidermis* (0.15-1.5 mm): outermost protective layer, renews fast, contains, e.g., pigment cells and keratin
  - *Dermis* (0.3-3.0 mm): beneath epidermis, contains, e.g., most of the skin receptors, nerve endings, capillaries
  - *Subcutaneous tissue* (thickness varies greatly): for insulation and storage of energy, contains, e.g., fat, nerves and larger blood vessels
Skin receptors

- There’s two different types of receptors responsible for tactile sensing found in the skin:
  - Free nerve endings
  - Encapsulated nerve endings (i.e., mechanoreceptors)

- Most tactile information is delivered via mechanoreceptors but, e.g., hair receptors also affect the sensations.
Mechanoreceptors 1/5

- Mechanoreceptors are sensitive to mechanical pressure and skin deformation
  - Differ in size, receptive fields, rate of adaptation, location in the skin, and physiological properties
  - Four types: Meissner’s corpuscles, Pacinian corpuscles, Merkel’s disks and Ruffini endings
Mechanoreceptors are generally specialized to certain stimuli

- Contact forces are detected by Merkel’s discs and Ruffini endings
- Vibration primarily stimulates the Meissner’s corpuscles and Pacinian corpuscles
Mechanoreceptors have different spatial resolutions

- *Spatial resolution* depends on the skin location (i.e., what and how many receptors are found in the locus)
- The size of the receptive field depends on how deep in the skin the particular receptor type lies (i.e., the deeper the receptor lies the larger is the receptive field)

**type I** receptors have large receptive fields (low spatial resolution)

**type II** receptors have small receptive fields (good spatial resolution)
Mechanoreceptors 4/5

- Receptors are divided into two categories based on their *speed of adaptation*
  - *Slowly adapting* (SA) receptors detect constant stimulus (e.g., pressure & skin stretch)
  - *Rapidly adapting* (RA) ones detect only short pulses (e.g., initial contact & vibration)
Mechanoreceptors 5/5

- Thresholds of different receptors overlap
  - In the brain the sensation is determined by the combined inputs from different types of receptors
  - Operating range for the perception of vibration is about 0.04 to 500 Hz (for hearing about 20 - 20000 Hz)

- Frequencies over 500 Hz are felt more as textures, not vibration
  - Skin surface temperature affects perceiving tactile sensations (inhibits or excites individual receptors)
Hairy vs. hairless skin

- Hairy skin is generally less sensitive to vibration compared to glabrous skin
  - There seems to be no Pacinian receptors in the hairy skin
    (however, they are present in the deeper underlying tissue
     surrounding joints and bones)

- Hairy skin is poorer to detect both vibration & pressure
  - Yet has about the same capacity for discriminating vibrotactile frequencies
Tactile dimensions

- Tactile acuity (vibration & pressure)
- Spatial acuity
- Temporal acuity
About thresholds

• Threshold means the point at which touch stimulation is consciously experienced
  - Detection threshold *(the smallest detectable level of stimulus; a.k.a. absolute threshold)*
  - Difference threshold *(the smallest detectable difference between stimuli; a.k.a. just noticeable difference or JND)*

• To reduce the detection threshold:
  - Increase the duration of the tactile stimulation
  - Increase the area of stimulation
  - Increase the temporal interval of two consecutive stimuli
Tactile acuity for vibration

- Vibration primarily stimulates the Pacinian corpuscles and Meissner’s corpuscles
  - Pacinian channel (high frequency, from about 60 Hz)
  - Non-pacinian channel (low frequency, below 60 Hz)

- Human sensitivity for vibration:
  - Sensitivity for mechanical vibration increases above 100 Hz and decreases above 320 Hz
  - 250 Hz is said to be the optimum
Tactile acuity for pressure

- Pressure stimulates mainly the Merkel’s disks

- Sensitivity for pressure is largely dependent on the location of stimulation
  - Discrimination resolution is higher at those parts of the body with a low threshold (e.g., fingertips)

- The face is being reported to have the smallest detection threshold
  - About 5 mg (5/1000 of a gram) in weight
  - Equals dropping a wing of a fly from 3 cm onto the skin
Tactile acuity for pressure and vibration

- Threshold responses for pressure (bars) and 200 Hz vibration (dots) for 15 body sites
  - Human body is highly sensitive to vibration
  - Vibration thresholds correlate with the density of cutaneous mechanoreceptors
Age and tactile acuity

- There appears to be no significant reduction in vibrotactile detection at the fingertips of older people
- Pressure sensitivity reduces as a function of age
- Training can be used to improve sensorimotor performance
Spatial acuity 1/2

- Fingertips are the most sensitive part of the human hand in texture & vibrotactile perception
  - Reported to have the largest density of PC receptors
  - The more spatially distant two stimuli are, the more difficult it is to compare them

- Tactile texture perception is mediated more by vibrational cues for fine textures, and by spatial cues for coarse textures
  - When using hand, exploration of spatially varying surfaces is done with larger area of skin (increased sensitivity by active touch)
Spatial acuity 2/2

- Spatial dimensions of touch
  - Two-point threshold
    (*two simultaneous points of stimulation*)
  - Point localization
    (*two consecutive points of stimulation*)
  - Grating discrimination
    (*detectable difference between two gratings*)

- Why do people do better with gratings than two-point discrimination?
  - Active vs. passive touch
Spatial acuity for pressure

- Spatial thresholds (in mm) for two-point discrimination (bars) and point localization (dots) for 14 body sites
  - Smallest threshold in facial area & hands
  - Threshold for point localization lower throughout the body
Temporal acuity

- Temporal resolution for touch with two successive stimuli is about 5 ms
  - For comparison:
    Audio: about 0.01 ms for clicks
    Vision: about 25 ms

- Resolution for tactile numerosity is reported to lie between 1 to 5 pulses (with intervals of 20 and 100 ms)
  - At brief intervals two pulses presented to the same location may mask one another
Pain and temperature

• Pain receptors (nociceptors)
  - Nerve endings sensitive to mechanical, thermal or chemical stimuli
  - Provide highly important information for avoiding accidents

• Temperature receptors (thermoreceptors)
  - Around 30 cold receptors per one warm receptor
  - Warm receptors are most responsive at 45°C, cold receptors at 27°C
  - More responsive to a change in temperature than to a constant temperature
Thermotactile interactions 1/2

- Temperature and touch have interactions even though being separate modalities
- Thermal cues are important in identification of objects
Thermotactile interactions 2/2

• **Thermal adaptation**
  - Cooling degrades tactile sensitivity
  - Warming sometimes enhances

• **Thermal intensification**
  - Cold objects feel heavier
  - Warm objects feel heavier but less than cold ones

• **Thermal sharpening**
  - The warmer or colder the two points are, the easier they are to discriminate
Touch is not an absolute sense

- Several factors affect the touch sensitivity:
  - Age
  - Sex
  - Individual differences
  - Attention, fatigue, mood, stress
  - Diseases, disabilities
  - Training

⇒ Scalability is an important factor in tactile interfaces!
Haptic perception
Haptic perception integrates somatosensory information in recognizing objects

- Touch mediates material properties (e.g., texture, hardness & temperature)
- Proprioception provides spatial and motor information (e.g., object geometry & hand position)

The perceived frequency of the grating depends on

1) The physical frequency of stimulation, and
2) Information about how fast the finger is being moved across a surface
Vision vs. touch simplified:
- Vision more capable of providing geometric information & general picture
- Touch more effective in providing material information & fine surface details

Different strategies for touching
- Active touch (focus on the object properties)
- Passive touch (focus on the sensation experienced)
Active vs. passive touch

- “The great cookie-cutter experiment” by Gibson (1962)
  - Experimenter pushes a cookie cutter onto participant’s palm
    ⇒ 49% correct identification
  - Participant actively feels cookie cutter with the palm
    ⇒ 95% correct identification

- Demonstrated that active exploration is essential in our ability to perceive objects in the physical world
Exploratory procedures

- Exploratory procedures defined by Lederman & Klatzky (1987)
  - These stereotypical ways of touching enhance the relevant perceptual information (see a video)
An example: real-world exploration

Blind biologist and paleontologist: Geerat Vermeij, Professor of Geology, UC Davis
- Born with a childhood form of glaucoma, completely blind from the age of three
- Geerat does all his work with his hands; his heightened awareness of shape and texture has allowed him to observe distinctions that sighted biologists easily overlook