The Somatosensory System
General Topics

Chapter 3 in text

- Touch
- Thermal sensations
- Proprioception & Kinesthesia
- Pain
Touch Teaches Us About Other Senses

- Multimodality
- Transduction
- Parallel vs. Serial processing
- Receptive fields
- Temporal and spatial resolution
Touch: Subtopics

- The stimuli of touch
- Anatomy of the skin
- Types of mechanoreceptors
- Brain areas processing touch sensations
- Tactile acuity and vibration sensitivity
- Haptic object perception
The Many Stimuli of Touch

• Somatosensory neurones respond to physical changes in skin, mainly involving:
• Pressure (stretch & compression)
• Vibration (movement)
• Temperature (cold or heat)
• These combine to elicit higher-order sensations such as wetness or smoothness
Pressure

• Measured in Pascals (N/m$^2$) or, if area is kept constant (and gravity), can be measured in grams (g)

• Pressure thresholds vary depending on many factors, such as speed and depth/distance of skin deformation, body location, area of skin affected, etc.
Vibration

- Variations in skin pressure across time
- Frequency of vibration is measured in Hertz (Hz) = cycles/second
- Amplitude of vibration measured in meters (usually µm)
- The basis for the sense of movement across the skin, which is important in (e.g.) tool use
Temperature

• Measured in degrees Celsius (C°)

• Decreases or increases from physiological zero (≈32 C°) are detected respectively by cold and warmth thermoreceptors.

• Threshold for detection depends on rate of change (C°/s) and area of skin (cm²) affected, among other things.
Pain

- Excessive intensities of pressure, vibration, and temperature (as well as pH) produce painful sensations.
- The pain threshold varies according to many factors.
- Pain is in general a very complex and subtle topic.
Anatomy of Skin

- Heaviest and largest sense organ by far
- Two main layers:
  - Epidermis: Outer layer, made up mainly of keratinized skin cells
  - Dermis: Below the epidermis. Contains three categories of mechanoreceptors
- Two types of skin: Hairy and hairless (no, shaving doesn’t change the type), with different elastic properties.
Skin & (some) Mechanoreceptors

- Epidermis
- Dermis
- Subcutaneous fat
- Merkel receptors
- Duct of sweat gland
- Ruffini cylinder
- Meissner corpuscle
- Pacinian corpuscle
Mechanoreceptors

• Sensory neurones. Signal pressure on skin
• Respond to *mechanical deformation* of the receptor or associated structure
• Three main categories:
  • Encapsulated
  • Accessory-structure-associated
  • Free nerve endings
Encapsulated Mechanoreceptors

- Meissner corpuscle
- Ruffini corpuscle
- Pacinian corpuscle

- Each of these is a neurone with a specialized ending growing out of its dendrite(s)
Mechanoreceptors w/ Accessory Structures

- Merkel Disc: Dendrites from mechanoreceptor surround a separate skin cell called a Merkel cell
- Root Hair Plexus: Dendrites surround follicle

- These neurones lack a specialized ending, instead relying on contact with a separate structure. (we will see this idea again in proprioception)
Free Nerve Endings

• Simply neurones with extensions* that terminate close to skin’s surface

• No corpuscle or accessory structure

• Some are mechanoreceptors, but:
  • Some respond to heat and/or cold (thermoreceptors)
  • Others signal various sorts of pain (nociceptors)

* FNE “extensions” are not (strictly speaking) dendrites, for reasons we’ll get into later...
Questions?

• What are the three main types of mechanoreceptors?

• What are the two main layers of skin?
From Skin to Spine

- When appropriately stimulated, mechanoreceptors produce action potentials.
- These are transmitted to the spine by *dorsal root ganglion* neurones, a type of *bipolar neurone*.
DRG Neurones

• Come in two basic types: A (myelinated) and C (unmyelinated)

• The A type is further broken down into
  • \(\alpha\) (alpha): Big diameter, very fast transmission \((\approx 100 \text{ m/s})\). Connect to proprioceptors (about which, more later).
  • \(\beta\) (beta): Medium diameter and transmission speed \((\approx 50 \text{ m/s})\), carry info from all mechanoreceptors but free nerve endings
  • \(\delta\) (delta): Small diameter, slow transmission \((\approx 20 \text{ m/s})\). Carry signals from some free nerve endings (e.g. cold thermoreceptors)
  • C fibres: Smallest and slowest \((\approx 0.5 \text{ m/s})\), so up to 4s from toe to brain), 100 times slower than A\(\alpha\). Carry pain and warmth signals.
Another way to classify DRG neurones is by how fast they adapt to stimuli. Two basic types:

- Fast adapting (FA): Respond at onset and offset of stimulus
- Slow adapting (SA): Respond continuously to stimulus
DRG Neurones

- FA and SA further break down based on depth in skin:
  - FA-I & SA-I are found near surface. Have small receptive fields
  - FA-II & SA-II are found deeper. Have large receptive fields

<table>
<thead>
<tr>
<th>Mechanoreceptor</th>
<th>Skin Location</th>
<th>Fibre Type</th>
<th>Response Type</th>
<th>RF Size</th>
<th>Perceptual Impression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merkel</td>
<td>Superficial</td>
<td>Aβ</td>
<td>SA-I</td>
<td>Small</td>
<td>Steady pressure</td>
</tr>
<tr>
<td>Meissner</td>
<td>Superficial</td>
<td>Aβ</td>
<td>FA-I</td>
<td>Small</td>
<td>Flutter; motion</td>
</tr>
<tr>
<td>Ruffini</td>
<td>Deep</td>
<td>Aβ</td>
<td>SA-II</td>
<td>Large</td>
<td>Steady pressure &amp; Stretch</td>
</tr>
<tr>
<td>Pacinian</td>
<td>Deep</td>
<td>Aβ</td>
<td>Mixed</td>
<td>Large</td>
<td>Vibration</td>
</tr>
<tr>
<td>Free nerve endings</td>
<td>Superficial</td>
<td>Aδ &amp; c</td>
<td>Mixed</td>
<td>Variable</td>
<td>Warmth; cold; sharp pain; burning pain</td>
</tr>
</tbody>
</table>
Fundamental Concept: Receptive Field

- The area of a sense organ affecting the firing of a given neurone
- Applies to all sense organs: Skin, retina, inner ear, etc.
- Determined by measuring neurone firing via microelectrode and then hunting around on the surface for areas that affect firing rate.
- Can have excitatory and inhibitory components, often in “centre/surround” organization.
- Note that RFs overlap one another and that any given receptor is usually part of multiple higher-level RFs
Centre-surround RF

- Area of skin or retina that affects firing of a given neurone.
- Varies in size and has either an excitatory centre/inhibitory surround or inhibitory centre/excitatory surround.
Fundamental Concepts: Temporal & Spatial Resolution

• Spatial Resolution: How many receptors are there across an area of the sense organ? Determines (in part) how precisely one can know \textit{where} a stimulus happened.

• Temporal Resolution: How often does a given receptor respond to stimuli? Determines how precisely one can know \textit{when} a stimulus happened.
RF Size & Spatial Resolution

• The size of the RF determines the upper limit of spatial resolution.

• Think about pixel size and resolution on a monitor

• RF size does not (directly) affect temporal resolution.
RF Size & Spatial Resolution

Stimuli

Receptive Fields

Mechano-receptors
# Temporal vs. Spatial Resolution & The Mechanoreceptors

<table>
<thead>
<tr>
<th>Mechanoreceptor</th>
<th>RF size</th>
<th>Spatial Resolution</th>
<th>Adaptation</th>
<th>Temporal Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merkel</td>
<td>Small</td>
<td>High</td>
<td>Slow</td>
<td>Low</td>
</tr>
<tr>
<td>Meissner</td>
<td>Small</td>
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<td>Large</td>
<td>Low</td>
<td>Fast</td>
<td>High</td>
</tr>
<tr>
<td>Free nerve endings</td>
<td>Varies</td>
<td>Varies</td>
<td>Varies</td>
<td>Varies</td>
</tr>
</tbody>
</table>
Temporal vs. Spatial Resolution

• Why not just Meissner? Resolution isn’t the whole story. Sensitivity is often traded off with resolution.

• Also, some receptors are specialized for particular important types of stimuli (e.g., Ruffini endings detect skin stretch)
Review: Anatomical Directions
Review: Anatomical Directions in the Brain & Spine
Review: Anatomical Directions in the Brain & Spine
Questions?

- What is a receptive field?
- In what direction are one’s arms relative to one’s sternum (two correct answers).
- What is the relationship between RF size and spatial resolution?
From Skin to Brain: Parallel Pathways

**Dorsal Column-Medial lemniscal pathway**
- large fibres ($A^\alpha$ & $A^\beta$)
- cross over the medial lemniscus of brainstem
- carry kinesthetic and tactile information
- fast conduction
- evolutionarily newer

**Anterolateral pathway**
- small fibres ($A^\delta$ & C)
- cross over in the spine
- carries temperature and pain information
- slow conduction
- evolutionarily older
Dorsal Root Ganglion
DRG Neurones
Anterolateral tract
Medial lemniscus
Dorsal root
Spinal cord
Touch
Thalamus
Ventrolateral nucleus
Somatosensory cortex
Fundamental Concept: Serial & Parallel Processing

- Serial processing: Neurones connect to one another in sequence. E.g., DRG neurones connect to spinal ones, which connect to ones in thalamus, which connect to S-I, etc.

- Parallel processing: Several streams or channels of neurones, each dealing with different aspects of perception, bring information to the brain simultaneously. The channels tend to be only semi-independent, however.

- This kind of arrangement is found in all sensory systems.
Fundamental Concepts of Sensory System Organization

• *Contralateral* Processing: Sensations from left side of body cross over to right side of brain, and vice versa.

• However, signals are then communicated to *ipsilateral* side, so that the whole brain is (normally) involved.

• Topographic Organization: Neurones from adjacent parts of sensory organs synapse with adjacent neurones in brain modules (*somatotopic, retinotopic*, etc.)
Somatotopic Organization

- Throughout the somatosensory system, adjacent neurones/fibres carry signals from adjacent parts of the body.
- It didn’t have to be this way (information doesn’t care where it is located) but evolutionarily this is the way it turned out.
- The size of brain areas is related to number of receptors in an area, not the size of the area.
Subcortical Regions in Touch

- Spinal neurones from the *medial lemniscal* pathway (touch), terminate in the ventral posterior nucleus (VPN) of the thalamus

- All senses have thalamic relay nuclei except smell

- *Anterolateral* pathway (pain, temperature) neurones terminate in several subcortical areas, which in turn send projections to many parts of the brain

- This diffuse connectivity reflects the importance of pain signals
Somatosensory Cortex
Subareas of Area S-1

- Proprioceptive
- Tactile
- Tactile & Proprioceptive

Diagram illustrating the subareas of Area S-1.
**Fundamental Concept: Integration**

- Although sensory signals are initially processed in separate parallel streams, they eventually rejoin.
- Presumably they interact to perform more complex, higher-order sensory analyses.
- Example: Subarea 2 of S-I integrates proprioceptive and tactile stimuli.
- Integration is seen in all sensory systems.
Questions?

• Where are DRG neurone cell bodies located?

• Which subarea of S-I first processes tactile stimuli? Which first processes proprioceptive stimuli.

• Mechanoreceptor signals are primarily carried by what class of DRG neurons?
Organization of Neurones within Somatosensory Cortex

• Signals from thalamus go to somatosensory receiving area 1 (S-I) and the secondary receiving area (S-II) in parietal lobe

• Body map (homunculus) on the cortex shows more cortical space allocated to parts of the body that have more receptors (as in other senses)

• Multiple homunculi found in S-I and S-II (not PPC)

• Neural plasticity leads to changes in how cortical cells are allocated to body parts
Area of S1 receiving signals from body parts
Receptive Fields of Cortical Neurones

- Each cortical neurone receives inputs from a limited patch of skin. This is its RF.
- The shape and size of the RFs vary according to the area of the body. E.g., for the back the RFs are large, for the fingertips very small.
- The RFs also vary from one cortical area to another, becoming more complex in shape as one goes from S-I 3 to to S-II or PPC.
Tactile Receptive Fields Vary in Size Across the Body
Columnar Organization of Somatosensory Neurones

- Going downward through the 6 layers of the cortex in one spot, one finds neurones that respond to the same location on the body and to the same kind of mechanoreceptor (i.e., FA or SA)

- Another example of parallel processing, and is found in all sensory modalities.
Columnar Organization of Somatosensory Neurones
Columnar Organization of Somatosensory Neurones
Neural Plasticity

• The organization of somatosensory cortex is not fixed, but can be changed by experience

• This has been shown by

  • Experimental evidence in monkey
  • The phenomenon of musician’s cramp (aka focal dystonia) in humans.
Merzenich et al. The homunculous can be modified by experience:

TOP: Areas in somatosensory cortex representing a monkey’s five fingers. Shaded area represents the index fingertip.

BOTTOM: Area representing the fingertip increased in size after this area was heavily stimulated.
Musician’s Cramp

- Focal dystonia or “musician’s cramp” - loss of skilled hand movements
- Research examining the cortex has found that musicians with this disorder have “fused” cortical areas belonging to the affected hand
- Probably due to the same kind of cortical plasticity as seen in Merzenich et al.
Focal Dystonia
Questions

- What are the two pathways that carry touch information to the brain?
- What areas of the body get the most representation in SI? Why?
- Why does focal dystonia happen?
Perceptual Aspects of Tactile Sensation

- Intensity and sensation (thresholds and magnitudes)
- Spatial factors (tactile acuity)
- Temporal factors (vibration and motion)
- Thermal sensations
Pressure Thresholds: Method

- 19th century researchers used calibrated horse hairs as touch stimuli
- 20th century researchers used nylon fibres
- Mechanical devices such as the Tactile Automated Passive Stimulation (TAPS) device are now used.
Absolute Thresholds

- Absolute thresholds for touch pressure vary by:
  - body location
  - speed of indentation
  - gender, age, skin condition, etc.
Difference Thresholds

- Weber did his earliest work on tactile difference thresholds
- The weber fraction varies from .02 to .30 depending on body location, methodology and other factors.
Tactile Acuity

Six tactile acuity gratings of different frequencies built into a cube (Med-core.com)
Tactile Acuity

- The ability to locate touch sensations on the body with precision is called *Tactile Acuity*

- Two methods are used in measuring tactile acuity
  - Two-point threshold
  - Grating acuity
Two-point Threshold

- Participant is touched with either one or two probes
- Distance between points is varied according to psychophysical methods
- Threshold is the minimum distance for discriminating between one point or two
- Older method
Grating Orientation

- Skin is touched with gratings of various spatial frequencies
- Participant’s task is to indicate orientation of grating (horizontal or vertical)
- Threshold is minimum spatial frequency needed for 75% accuracy.
- Newer method, possibly more reliable
- Note the use of gratings in touch and vision
Tactile Sensitivity

Tactile Acuity
There is a high density of Merkel receptor/SA1 fibres in the fingertips

Both two-point thresholds and grating acuity studies show high tactile acuity in these areas as well

(also, single-cell recordings show small RFs)
Relationship between density (1/spacing) of Merkel receptors (SA1 fibre density) and acuity.
Law of Outward Mobility
The Cortex and Tactile Acuity

- Body areas with high acuity have larger areas of cortical tissue devoted to them.
- This parallels the “foveal magnification factor” seen in the visual cortex for receptors in central vision.
- Areas with higher acuity also have smaller receptive fields on the skin.
Questions

- What area of the body has greatest tactile acuity? Why?
- What is the relationship between RF size and tactile acuity?
Perceiving Vibration
Perceiving Vibration

- Vibration sense is the basis for sensing motion across the skin.
- This comes into play in many physical activities, but especially when handling tools (e.g., writing with a pencil).
- It is important in locating and identifying any (moving) foreign bodies touching the skin.
Vibration is the Basis of Motion
Perceiving Vibration

- Pacinian and Meissner corpuscles are primarily responsible for sensing vibration.
- FA fibres associated with them respond best to low (Meissner) and high (Pacinian) rates of vibration.
- The corpuscle themselves are responsible for the response to vibration; FA fibres without the corpuscle only respond to pressure.
Displacement Thresholds

• Displacement thresholds vary with frequency of probe

• The overall function (top) is the product of the individual function of two different receptors (bottom)
Fundamental Concept: Channels and Envelope Functions

- Overall behaviour of a sensory system is often the product of several subsystems working together
- We call the subsystems (e.g., Meissner & Pacinian corpuscles) sensory channels
- The channels have individual psychophysical functions associated with them
- The overall behaviour is sometimes described as an envelope function (i.e., it “envelops” the functions of the individual channels; see previous slide).
Difference Thresholds for Frequency

- The Weber fraction for discriminating between vibration frequencies ranges from about .2 at 25 Hz to about .35 at 200 Hz.
- Thus, a 200 Hz stimulus would have to be raised to 270 Hz to produce a JND in the subjective sense of pitch.
Fundamental Concept: Perceptual Correlates

Each physical stimulus has an associated perceptual correlate, which is the subjective aspect of its sensation. Examples:

<table>
<thead>
<tr>
<th>Physical Intensity (I) Characteristic</th>
<th>Perceptual Correlate/Sensory Quality (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hearing &amp; Touch</td>
<td></td>
</tr>
<tr>
<td>Frequency (Hz)</td>
<td>Pitch</td>
</tr>
<tr>
<td>Vision</td>
<td></td>
</tr>
<tr>
<td>Luminance (cd/m²)</td>
<td>Brightness</td>
</tr>
<tr>
<td>Hearing</td>
<td></td>
</tr>
<tr>
<td>Sound Pressure (Pa)</td>
<td>Loudness</td>
</tr>
<tr>
<td>Smell &amp; Taste</td>
<td></td>
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<tr>
<td>Concentration (ppm)</td>
<td>Strength</td>
</tr>
</tbody>
</table>
Perceiving Tactile Texture

- Tactile texture sense is a higher-order perception involving pressure differences arising from patterns on surfaces.
- This sense arises when judging the roughness of a surface, the softness of fabric, etc.
- Important to a brachiating or tool-using primate
Duplex Theory of Texture Perception

• Based on behavioural evidence Katz (1925) proposed that perception of texture depends on two cues:
  • Spatial cues are determined by the size, shape, and distribution of surface elements
  • Temporal cues are determined by the rate of vibration as skin is moved across finely textured surfaces
• He suggested that two receptors may be responsible for this process.
Duplex Theory of Texture Perception

- Research prior to Katz’s showed support for the role of spatial cues
- Recent research by Hollins and Reisner shows support for the role of temporal cues
- In order to detect differences between fine textures, participants needed to move their fingers across the surface
- Which receptor is responsible for this?
Hollins and Reisser (2000)
Fundamental Concept: Adaptation

- Stimuli that don’t change are adapted to. That is, our sense of them diminishes with time.
- This was originally thought to be due to fatigue of the receptors.
- But this is not the case. Some receptors continuously fire while stimuli are present.
- Instead, a more central mechanism is at play.
Duplex Theory of Texture Perception

- Hollins et al’s adaptation experiment: Participants’ skin was adapted with either:
  - 10-Hz stimulus for 6 minutes to adapt (fatigue) the FA1 fibres / Meissner corpuscles
  - 250-Hz stimulus for 6 minutes to adapt (fatigue) the FA2 fibres / Pacinian corpuscles
- Results showed that only the adaptation to the 250-Hz stimulus affected the perception of fine textures
Pacinian Corpuscles Needed for Fine Texture Discrimination

![Graph showing texture perception (% correct) for different adapting stimuli: None, 10 Hz, 250 Hz. RA1 (Meissner Corpuscles) and PC (Pacinian Corpuscles) are eliminated as the adapting stimulus changes.](chart.png)
Questions

• Why is vibration sense important?
• Which mechanoreceptor is primarily responsible for fine texture discrimination via vibration sense?
Thermal Sensations
Thermal Sensations

- In addition to pressure and vibration, the skin picks up sensations of cold and heat, which are generated by *thermoreceptors*.

- Unlike most other receptors, thermoreceptors react to *reduction* of thermal energy, which is sensed as cold.
Thermal Sensations

- Two types of thermoreceptors exist:
  - Cold receptors (connect to Aδ fibres)
  - Warmth receptors (connect to C fibres)
- Both respond when skin temp departs from physiological zero (about 32°C)
- Rate of firing also depends on rate of change
Thermal Sensations

- Psychophysical experiments on temperature sensation show:
  - Absolute thresholds as low as .0001 °C (!) when large areas of skin are stimulated
  - Power law exponent for heat and cold are 1.6 and 1.0
  - These values depend on location on body, size of area of skin stimulated, temp of skin, etc.
Thermal Sensations

• Like all senses, thermal sense shows adaptation (e.g., hot bath feels merely warm after a time)

• Warmth and cold receptors may compete in an opponent process, such that adapting one causes the other to become more sensitive

• Example: Place left hand in warm water, right in cold water. Then place both in room temp water. The left hand will feel cool, while the right feels warm.
Fundamental Concept: Opponent Processes

Before: C and W receptors at resting rate, balanced in competition, no external inputs

During: W receptors fire strongly in left and C receptors fire strongly in right. External inputs overcome the inhibition from the other type of receptor.

After: W in left hand “fatigued”, therefore less inhibition of C (which are otherwise at normal resting rate) therefore relatively more active, so hand feels cool. (vice-versa for right hand)
Proprioception
Proprioception

- Sense of one’s own body position and motion
- Distinct from *exteroception*, which is sense of the outside world and *interoception*, which is sense of internal body states (hunger, thirst, etc.)
- Includes *kinesthesia*, the sense of muscle flexion and joint position, and *balance*, the sense of the body’s orientation in space.
Kinesthesia

• Two types of proprioceptors underlie our sense of muscle flexion and joint position. Both involve accessory structures.

• Muscle spindle receptors: Aα fibres surround specialized muscle cells, detect stretch

• Golgi tendon organ: Aα fibres entwined around a specialized structure at the junction of muscle and tendon. Detect stretch and flexion of muscles.
From Muscles/Joints to Brain

- Most of the Aα fibres synapse with neurons in the dorsal column.
- A few are part of reflex loops and synapse with motor neurones in the spine (e.g., knee jerk)
- Proprioceptive signals ultimately reach cortex at subarea 3a of S-I.
Perceptual Aspects

- Proprioceptors are responsible for weight discrimination
- Weber did some of his earliest work on this, finding a weber fraction of 0.02
- The relationship between subjective effort and physical force shows response expansion, with a power law exponent of 1.7
Corollary Discharge

- In addition to proprioception, body position is signalled by corollary discharge signals (CDS’s).
- When a motor signal is sent from brain to muscle, a copy of that signal (a CDS) is sent to somatosensory cortex.
- The CDS and proprioceptive signals are compared to do error checking/correction, as well as compensate for external forces.
Haptic Perception of Objects

http://lims.mech.northwestern.edu/projects/fingertip/index.html
Haptic Perception of Objects

- Humans use active rather than passive touch to interact with the environment.
- Haptic exploration is the active exploration of 3-D objects with the hand (e.g., searching in pocket or bag for keys).
- It involves a wide range of brain areas, including those for sensation, motor movement, and cognition.
Haptic Perception of Objects

• Research shows that people can identify objects haptically in 1 to 2 sec

• Klatzky et al. have shown that people use exploratory procedures (EPs)
  • Lateral motion
  • Pressure
  • Enclosure
  • Contour following
Haptic Exploration Procedures
Physiology of Haptic Object Perception

- The firing pattern of groups of mechanoreceptors signals shape, such as the curvature of an object
- Neurones further upstream become more specialized
- Monkey’s thalamus shows cells that respond to center-surround receptive fields
- Somatosensory cortex shows cells that respond maximally to orientations and direction of movement (We will see parallels in vision)
Patterns of Firing Across Many Mechanoreceptors Signals Object Shape

Response of SA1 fibers in fingertip to touching a high-curvature stimulus. The height of the profile indicates the firing rate at different places across the fingertip.
Patterns of Firing Across Many Mechanoreceptors Signals Object Shape

Response of SA1 fibers in fingertip to touching a stimulus with a more gentle curvature
Subcortical Receptive Fields in Touch

Neurones in thalamus have centre-surround RFs

Again, we will see parallels in vision.
Cortical Receptive Fields in Touch
Physiology of Haptic Object Perception

• Monkey’s somatosensory cortex also shows neurones that respond best to grasping specific shapes

• Paying attention to the grasped object increases the response of these neurones
Shape-Selective Neurones in Monkey Cortex
Questions

- What are some common haptic exploration procedures and what information does each of them provide?
- How does the set-up of RFs in touch parallel that in vision?
Pain

http://painresearch.stanford.edu/patientinfo.html
Overview of Topics

• Types of pain
• Nociceptors
• The CNS and pain
• Cognitive effects on pain
Pain Perception

- Pain is a multimodal phenomenon containing:
  - A sensory component
  - An affective or emotional component
- Pain is generally protective. Individuals who cannot sense pain are in danger of frequent injury, even from everyday activities.
- Pain can, however, be pathological.
Pain vs. Injury

- Although pain is generally associated with injury or threat of injury, the correlation is weaker than most people think.
- Individuals can be severely injured without pain (e.g., if distracted).
- Small injuries can be surprisingly painful (e.g., paper cuts).
Three Types of Pain

- There are three main types of pain
  - Nociceptive
  - Inflammatory
  - Neuropathic
- Others, such as psychogenic pain, exist as well...
Nociceptive Pain

(a) Nociceptive pain

- Heat
- Chemical
- Pressure
- Cold
Nociceptive Pain

- Nociceptive pain is usually a result of high-intensity stimuli.
- It is a response to tissue damage or the threat of tissue damage.
- It is usually a healthy protective response.
Nociceptive Pain

• Nociceptors are the transducer of pain signals. A sub-type of free nerve ending

• A given nociceptor responds to one or more of the following:
  • Heat (e.g., from a flame or hot surface)
  • Painful chemicals (e.g., acids, capsaicin)
  • Pressure (including cutting pressure)
  • Cold (e.g., cold pressor test)
Inflammatory Pain
Inflammatory Pain

• Caused by damage to tissues and joints that releases chemicals that activate nociceptors (e.g., joints swell after injury)

• Inflammation is usually a healthy protective response by the body, but can be pathological (e.g., arthritis pain)
Neuropathic Pain

- Carpal tunnel syndrome
- Spinal cord injury
- Thalamic stroke
Neuropathic Pain

• Neuropathic pain - caused by damage to the central or peripheral nervous system, such as:
  • Brain damage caused by stroke
  • Spinal cord damage (esp. to anterolateral)
  • Repetitive movements which cause conditions like carpal tunnel syndrome

• Generally considered a pathological failure of the pain sensation system
The CNS and Pain Perception

- Signals from nociceptors travel up the anterolateral pathway and activate:
  - Subcortical areas including the hypo-thalamus, limbic system, and the thalamus
  - Cortical areas including S1 and S2 in the somatosensory cortex, the insula, and the anterior cingulate cortex
  - These cortical areas taken together are called the pain matrix
The Pain Matrix
Questions

- What are the two major modalities of pain?
- What are the three main types of pain? Which are generally healthy vs. pathological?
- Name the two pathways that carry cutaneous information. Which one primarily carries pain signals?
Cognition and Pain

- Thoughts and emotions can influence the degree of both physical and emotional modalities of pain.
- Hypnotic suggestion, expectations, distraction and visualization can all modulate pain levels.
Participants presented with potentially painful stimuli and asked to rate:

- The sensory pain intensity
- The emotional unpleasantness of the pain

Brain activity was measured while they placed their hands into hot water.

Hypnosis was used to increase or decrease the sensory and emotional components.
Hoffauer et al.: Results

- Suggestions to change the sensory intensity of pain led to changes in those ratings and in S1.
- Suggestions to change the emotional unpleasantness of pain did not affect the sensory ratings but did change:
  - Ratings of emotional unpleasantness
  - Activation in the anterior cingulate cortex
Hofffauer et al.: Results

(a) Hypnotic suggestion: change intensity of pain

(b) Hypnotic suggestion: change unpleasantness of pain
Cognitive Effects on Pain

• Expectation - when surgical patients are told what to expect, they request less pain medication and leave the hospital earlier

• Shifting attention - virtual reality technology has been used to keep patients’ attention on other stimuli than the pain-inducing stimulation
Cognitive Effects on Pain

• Content of emotional distraction from pain matters: Participants could keep their hands in cold water longer when pictures they were shown were positive.

• Individual differences: Some people report higher levels of pain than others in response to the same stimulus.

• This could be due to experience or to physiological differences.
Cognitive Effects on Pain

![Bar graph showing time hand kept in water (seconds) for different types of pictures: Positive, Neutral, and Negative.](image)
Questions

• Name some cognitive effects that can reduce pain.

• Hoffauer’s results regarding hypnosis and pain showed what?
Gate Control Theory

- Developed by “iconoclasts” Melzack and Wall in the 1960’s

- “Pain is in the brain” Pain is not a one-way simple reaction to stimuli

- Pain is multimodal, and involves a widely-distributed network of brain areas (the pain matrix)

“Doctor Pain” (a.k.a. Ron Melzack)
Gate Control Theory

• GCT suggests that inputs from nociceptors can be “gated off” at the spinal level by
  • Afferent tactile inputs (touching the injured location)
  • Top-down inputs (attentional modulation, etc.)
  • The idea that fibres other than those from nociceptors could be involved in pain was a radical idea at the time.
Since the 1960’s it has been discovered that things are more complex than GCT would suggest.

Still, GCT was highly generative as a theory because it led people to explore a more complex view of pain.

GCT has been credited with a revolution in attitudes towards pain management.
Opioids and Pain

- A number of endogenous and exogenous chemicals called opioids can reduce pain
- Endogenous opioids are called endorphins, these are released by
  - Painful experiences
  - Pleasurable/relaxing experiences
- Thus they likely play a key role in top-down influences on pain
Opioids and Pain

- Exogenous opioids (a.k.a. painkillers) such as morphine can also block pain
- Morphine mimics the activity of endorphins, activating the same receptors in S1, S2, etc.
- Fear of addiction led in the past to under-use, but studies show little risk of this in medical situations (e.g., Melzack’s work)
- Self-administration is now common and leads to less use of morphine
Naloxone

- Naloxone is a drug used to treat heroin/morphine overdose
- Previously used to treat addiction, but now being replaced with naltrexone
- Naloxone blocks endorphin receptor sites, causing increase in pain
- Also decreases the effectiveness of placebos, suggesting that endorphins play a role in the placebo effect
Emotional Pain

- Experiment by Eisenberger et al.
- Participants watched a computer game. Then were asked to play with two other “players” who did not exist but were part of the program.
- The “players” excluded the participant.
- fMRI data showed increased activity in the anterior cingulate cortex when participants reported feeling ignored and distressed.
- Some people take video games way too seriously!
Questions

- What does Melzack’s “Pain is in the brain” idea mean?
- What two general influences can modulate pain according to GCT?
- Define opioid, endorphin and naloxone.