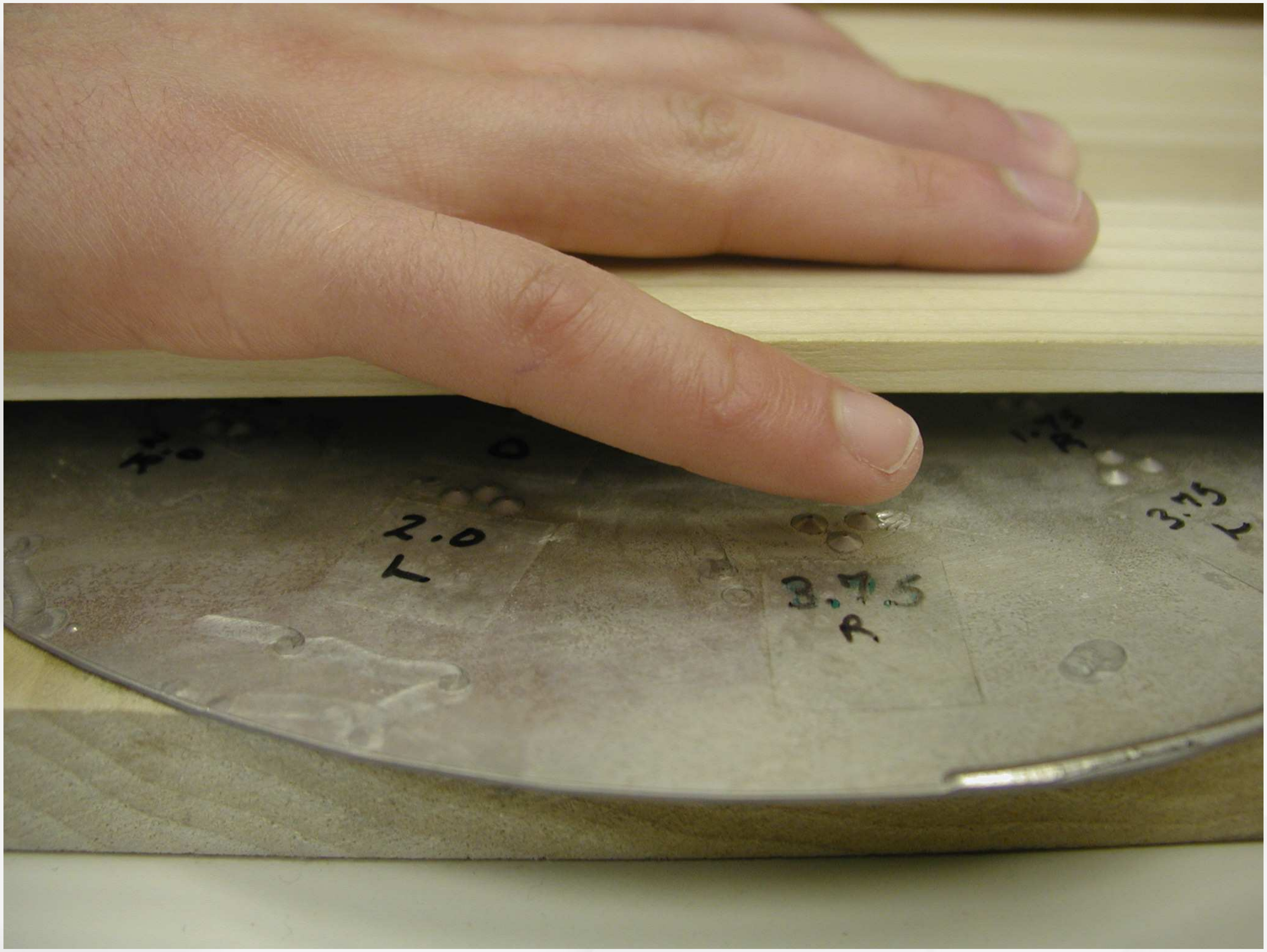
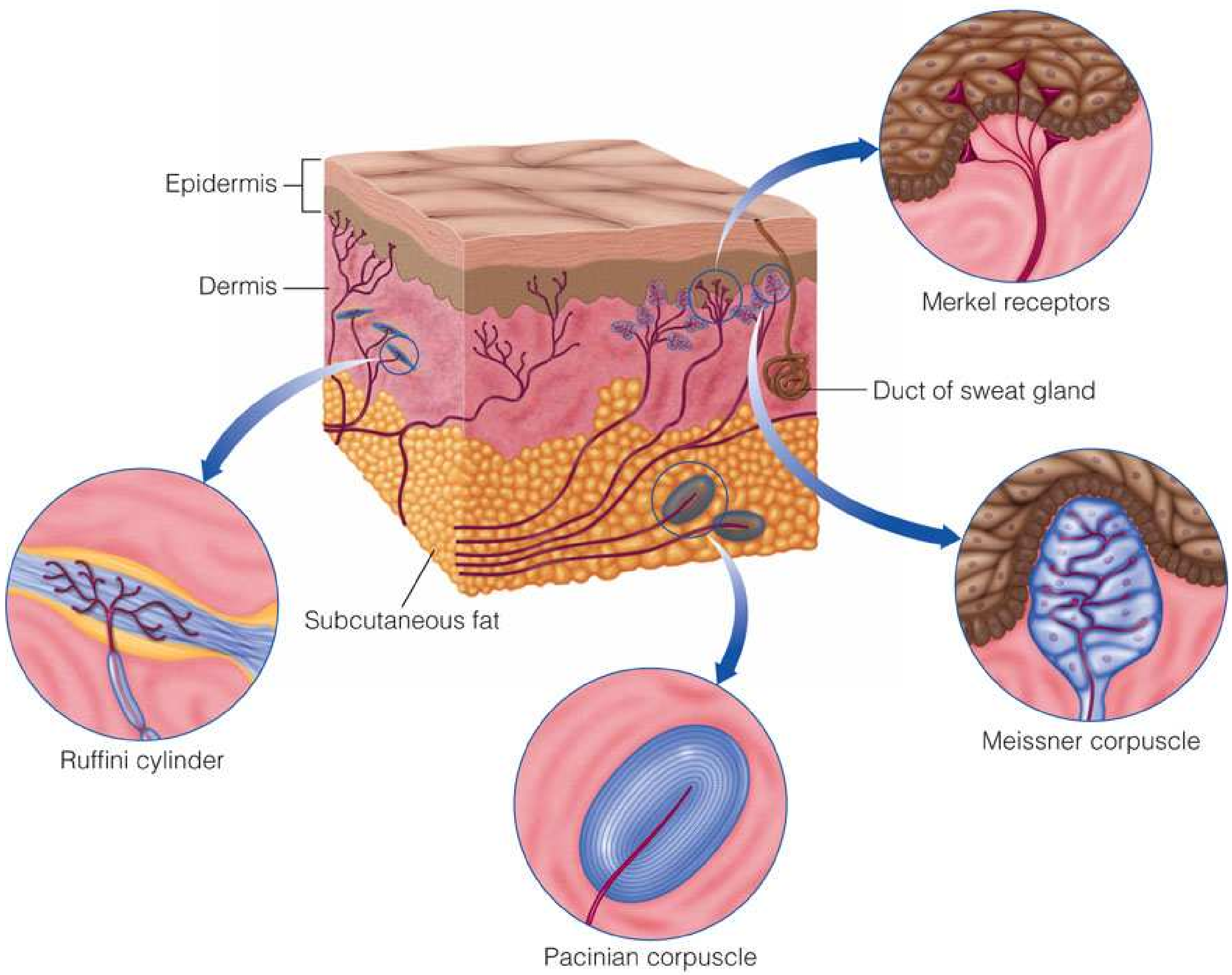
Chapter 14: The Cutaneous Senses



Cutaneous System

- **Skin** - heaviest organ in the body
  - Epidermis is the outer layer of the skin, which is made up of dead skin cells
  - Dermis is below the epidermis and contains four kinds of *mechanoreceptors* that respond to stimuli such as pressure, stretching, and vibration.



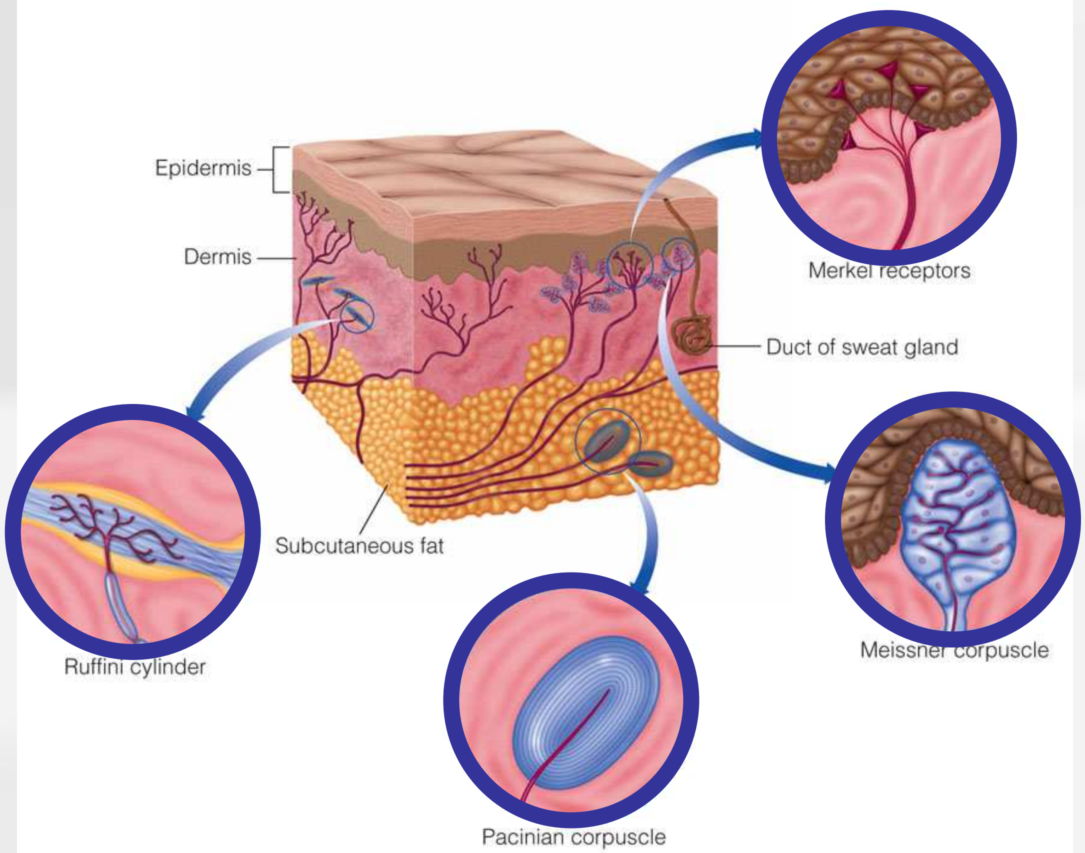
Mechanoreceptors

Merkel receptor - disk-shaped receptor located near the border between the epidermis and dermis

Meissner corpuscle - stack of flattened disks in the dermis just below epidermis

Ruffini cylinder - branched fibers inside a cylindrical capsule

Pacinian corpuscle - onion-like capsule located deep in the skin

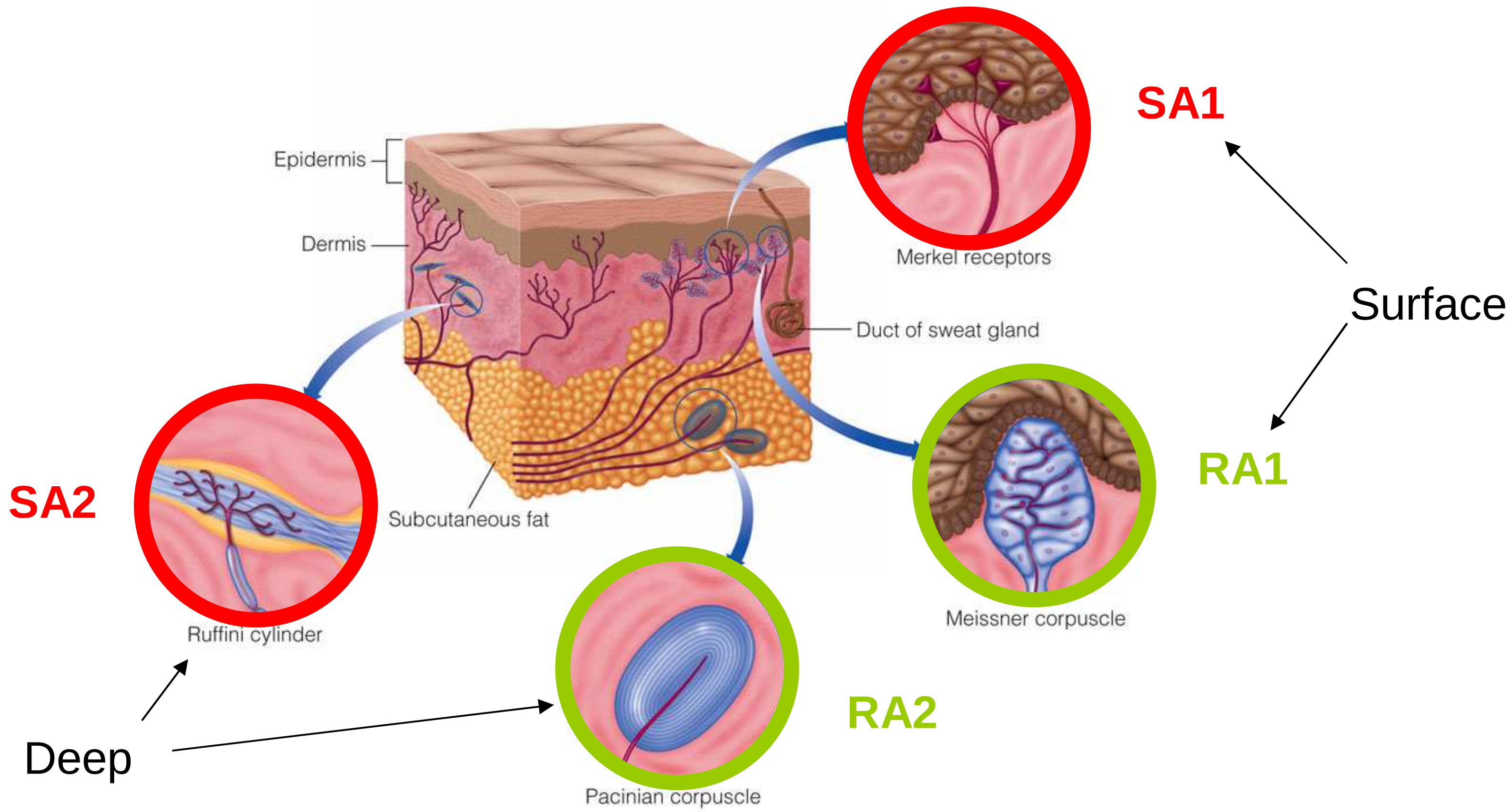


Mechanoreceptors

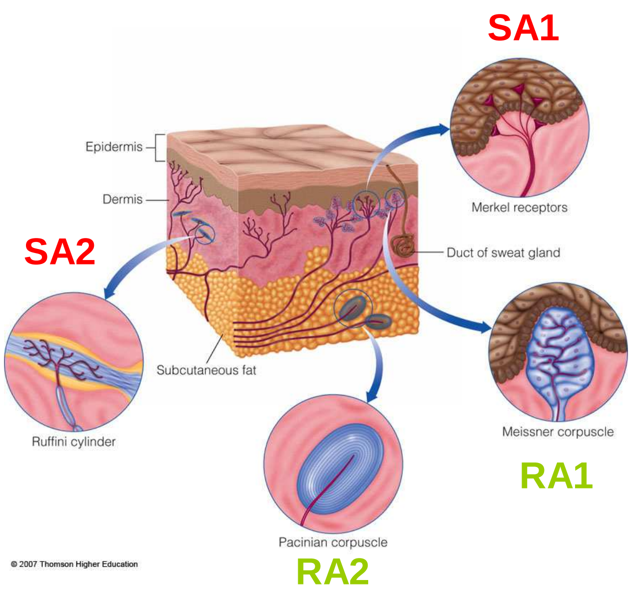
- Temporal Properties (adaptation)

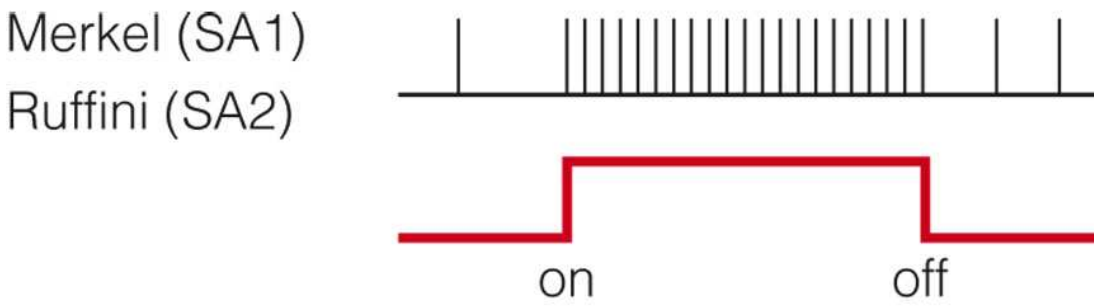
  - Slowly adapting fibers (SA) found in Merkel and Ruffini receptors - fire continuously as long as pressure is applied

  - Rapidly adapting fibers (RA) found in Meissner receptor and Pacinian corpuscle - fire at onset and offset of stimulation



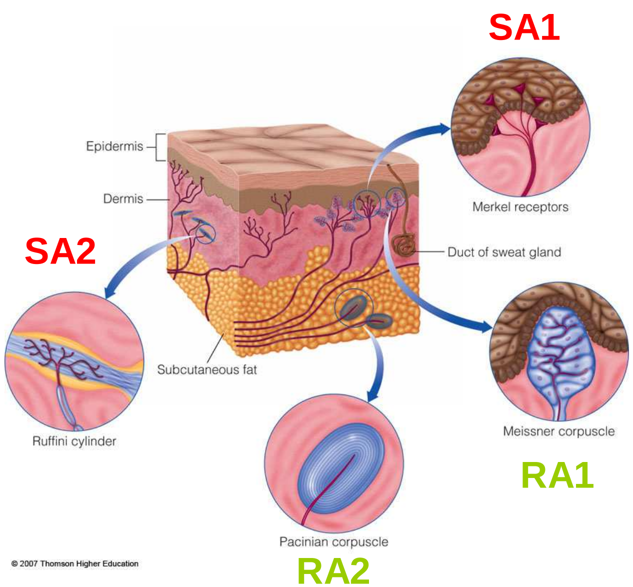
Mechanoreceptors





(a) Slow adapting (SA)

- Spatial Properties (detail resolution)



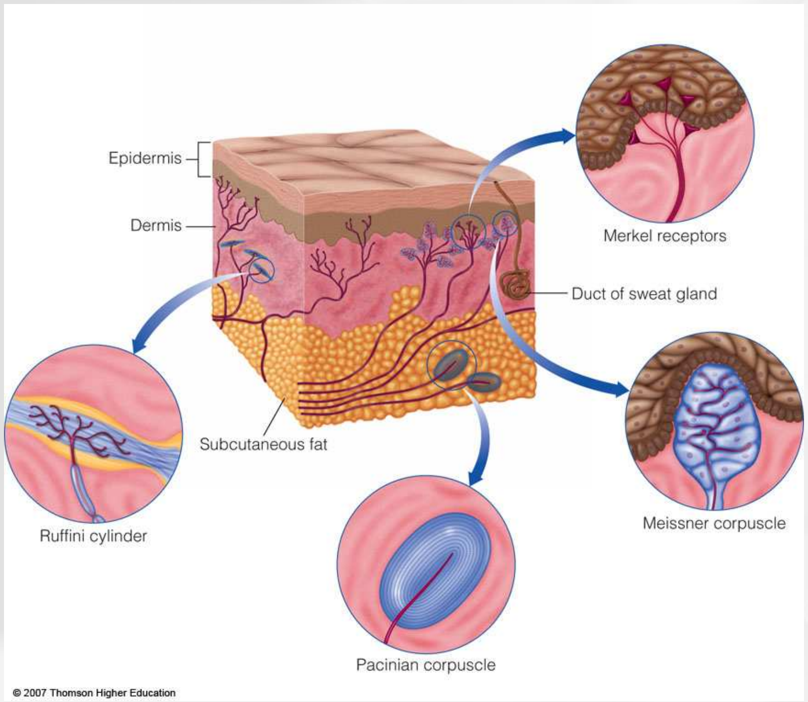
Surface receptors: Merkel receptors (SA1) and Meissner receptors (RA1) have small receptive fields and respond to slow vibration rates.

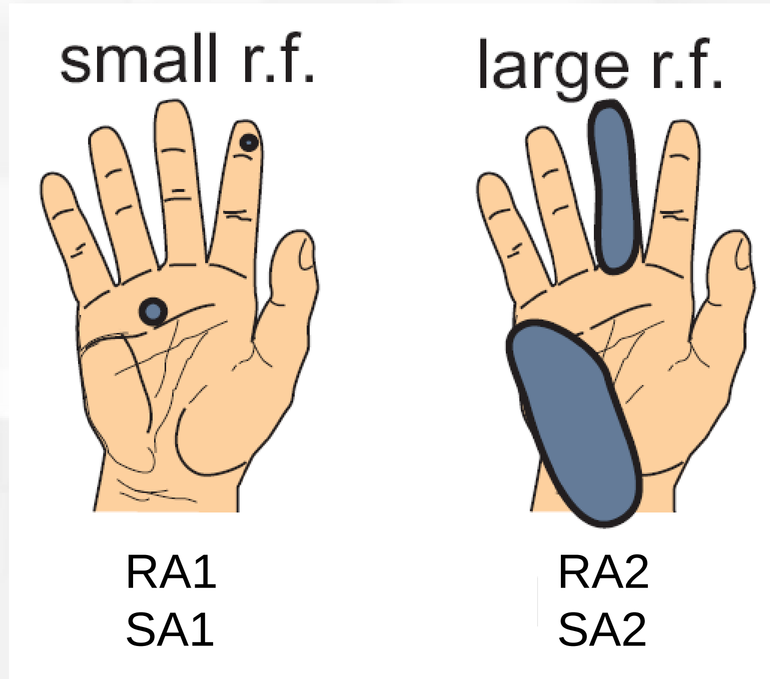
Deep receptors: RA2 fibers (Pacinian corpuscle) and Ruffini (SA2) have large receptive fields and respond to high vibration rates.

Adapting Rate

Vibration frequency	Slow	Rapid
Low	Merkel receptors (SA1)	Meissner receptors (RA1)
High	Ruffini (SA2)	Pacinian corpuscle (RA2)

Surface receptors have smaller receptive fields than deep receptors.





Properties of the four mechanoreceptor types.

Adapting Rate

Vibration Frequency	Slow	Rapid
Low	Merkel receptors (SA1)	Meissner receptors (RA1)
High	Ruffini (SA2)	Pacinian corpuscle (RA2)

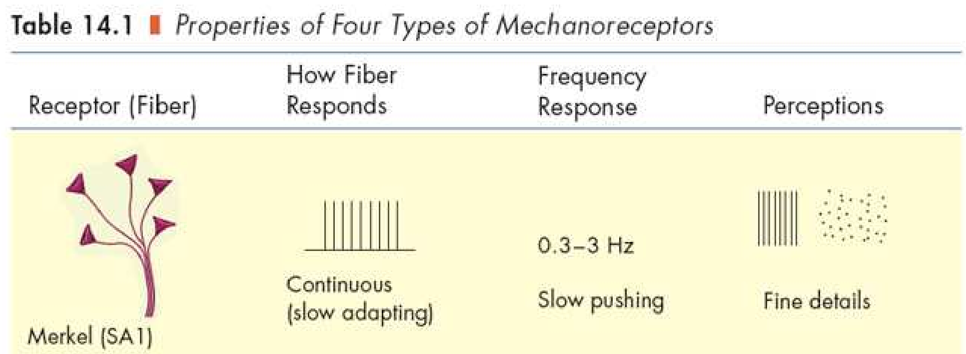
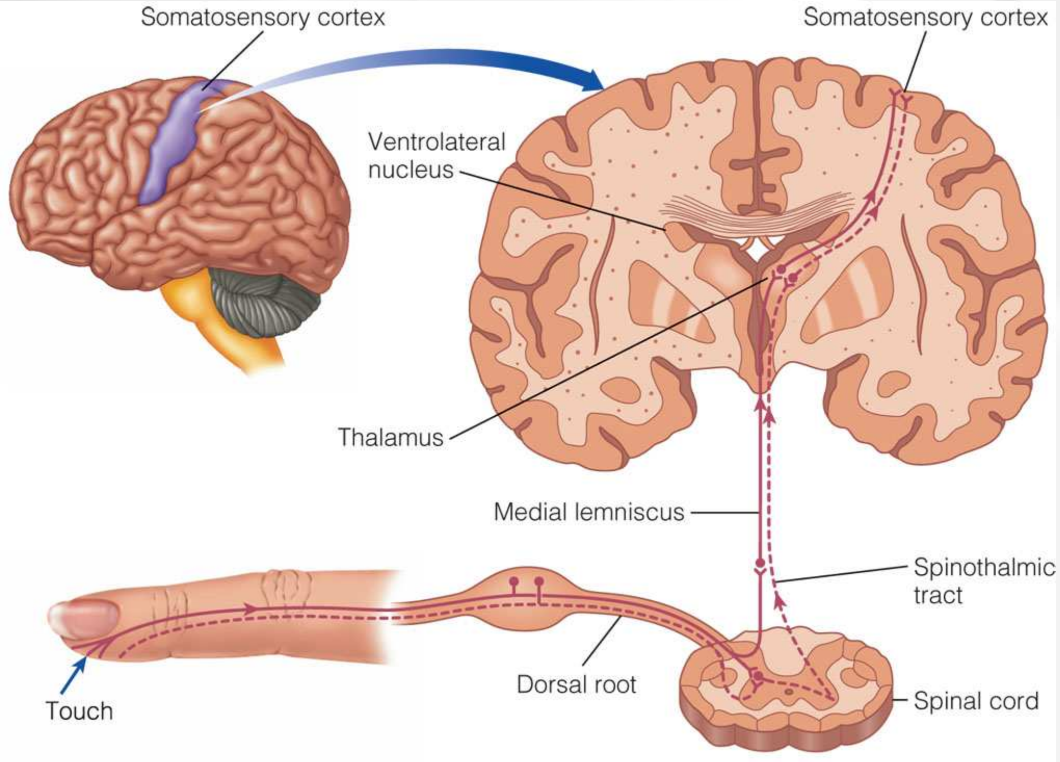


Table 14.1 *Properties of Four Types of Mechanoreceptors*

Receptor (Fiber)	How Fiber Responds	Frequency Response	Perceptions
Merkel (SA1)	Continuous (slow adapting)	0.3–3 Hz Slow pushing	Fine details

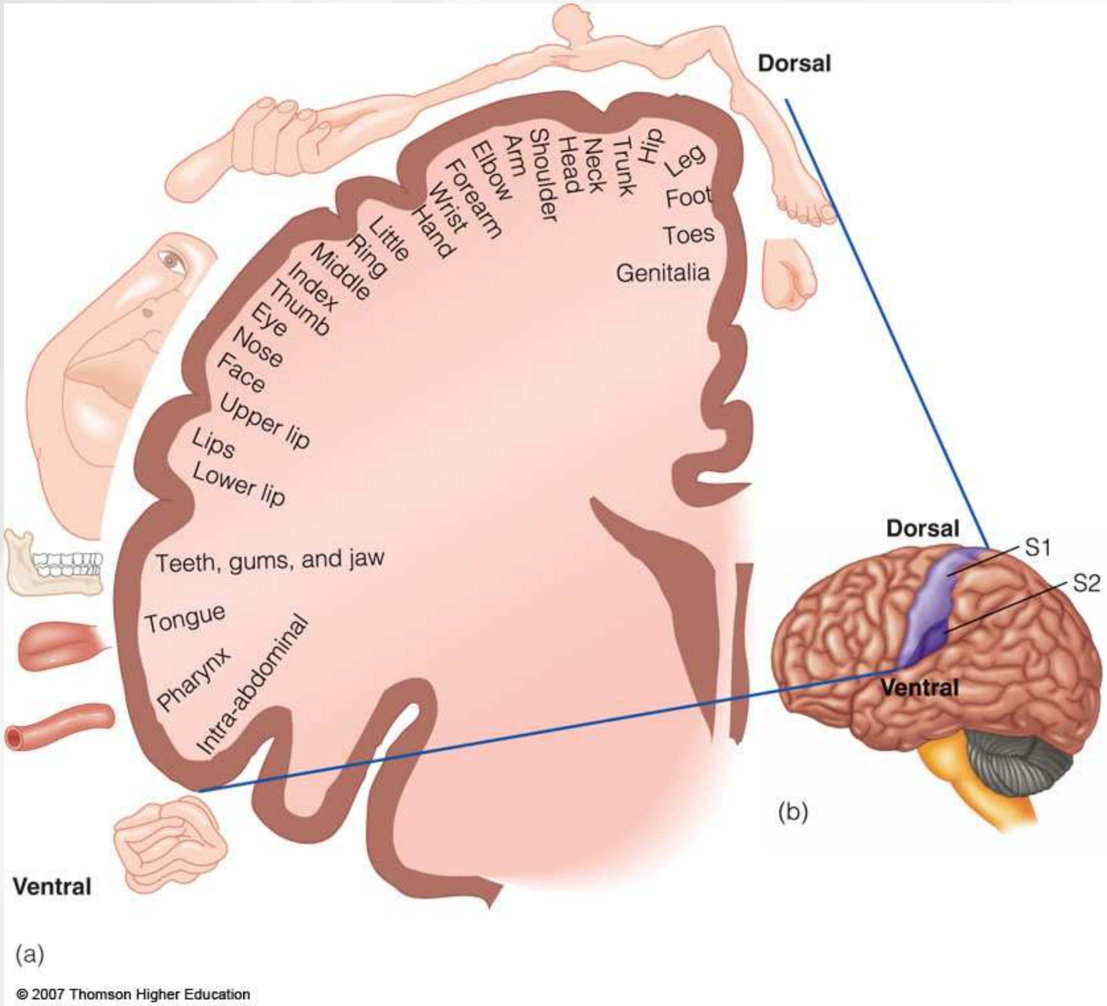
Pathways from Skin to Cortex

- Nerve fibers travel in bundles (peripheral nerves) to the spinal cord
- Two major pathways in the spinal cord:
  - Medial lemniscal pathway consists of large fibers that carry proprioceptive and **touch** information
  - Spinothalamic pathway consists of smaller fibers that carry temperature and **pain** information
  - These cross over to the opposite side of the body and synapse in the thalamus, and then on to the Somatosensory cortex, or SA1



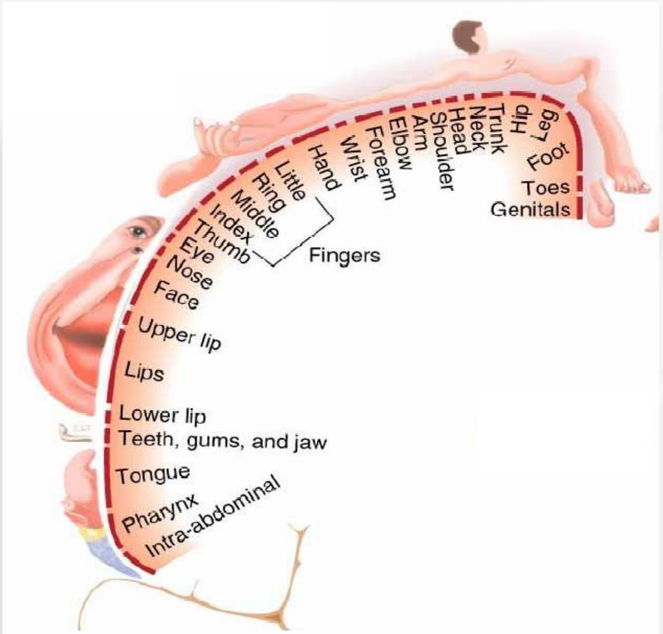
Maps of the Body on the Cortex

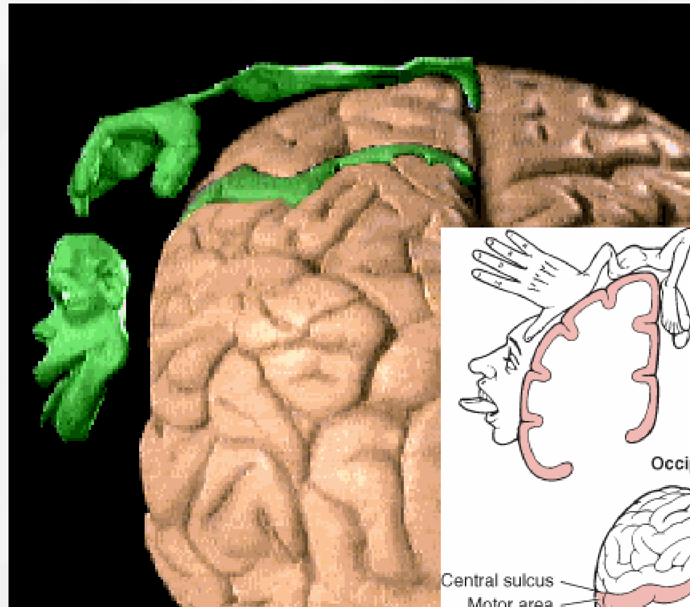
- Signals travel from the thalamus to the somatosensory receiving area (S1) and the secondary receiving area (S2) in the parietal lobe
- Body map (*homunculus*) on the cortex shows more cortical space allocated to parts of the body that are responsible for detail

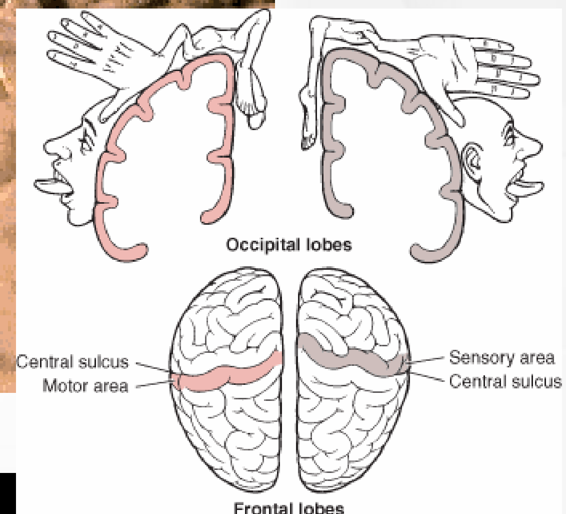


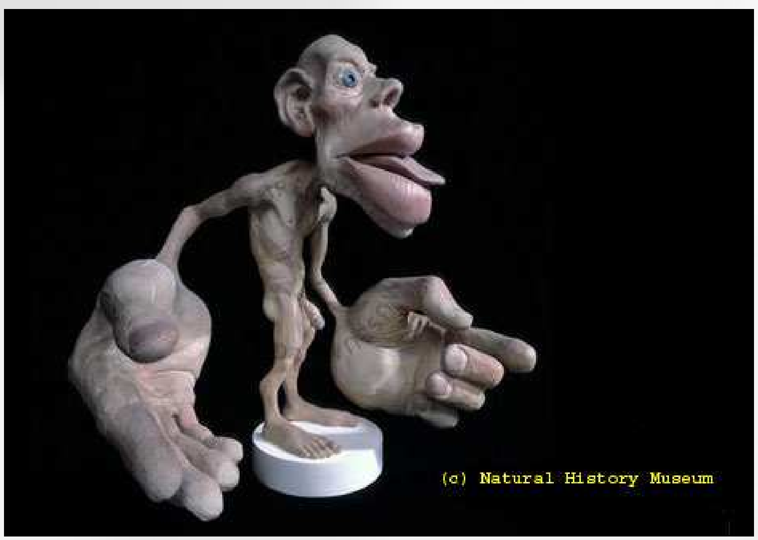
Discovered by Penfield in 1950

The ‘Somatosensory Homunculus’







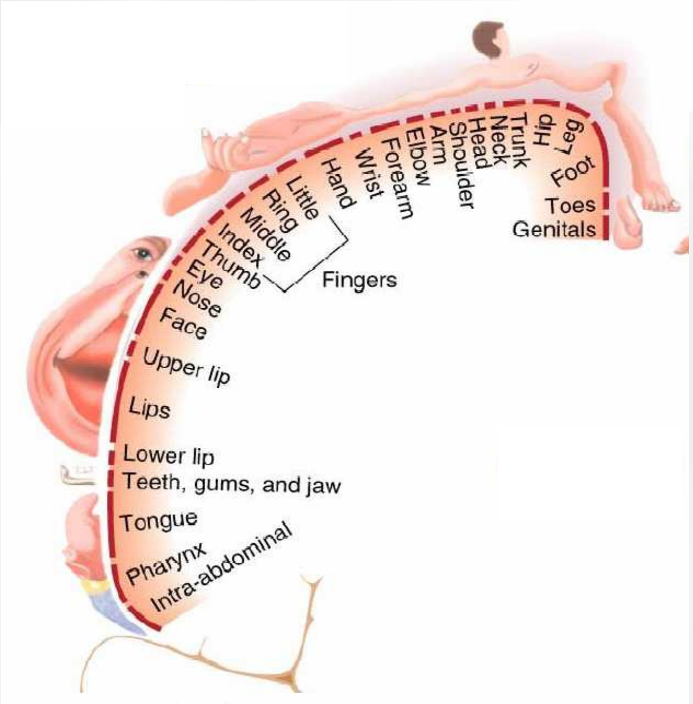


Phantom Limb Disorder

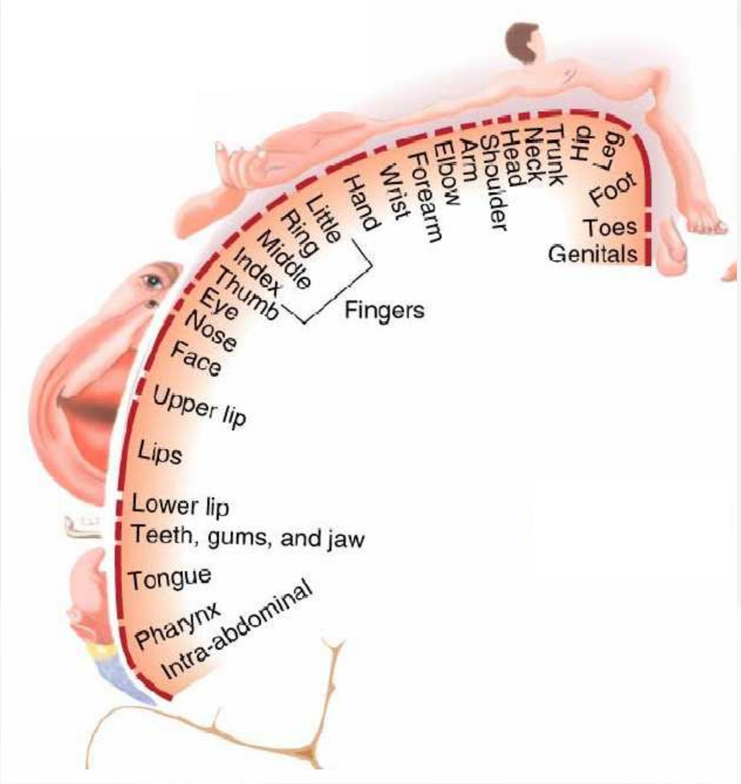
The persistent sensation of an appendage, after removal by amputation or simple denervation.

Ramachandran and colleagues has shown that touching the face of a phantom limb patient leads to sensations in the missing hand and arm.

This lead to the hypothesis that the brain is ‘filling in’ for the missing stimulation in the hand and arm representation in the somatosensory cortex.



Phantom Limb Disorder



Touching the chin stimulated the finger representation best, indicating that maybe Penfield got the face representation upside down.

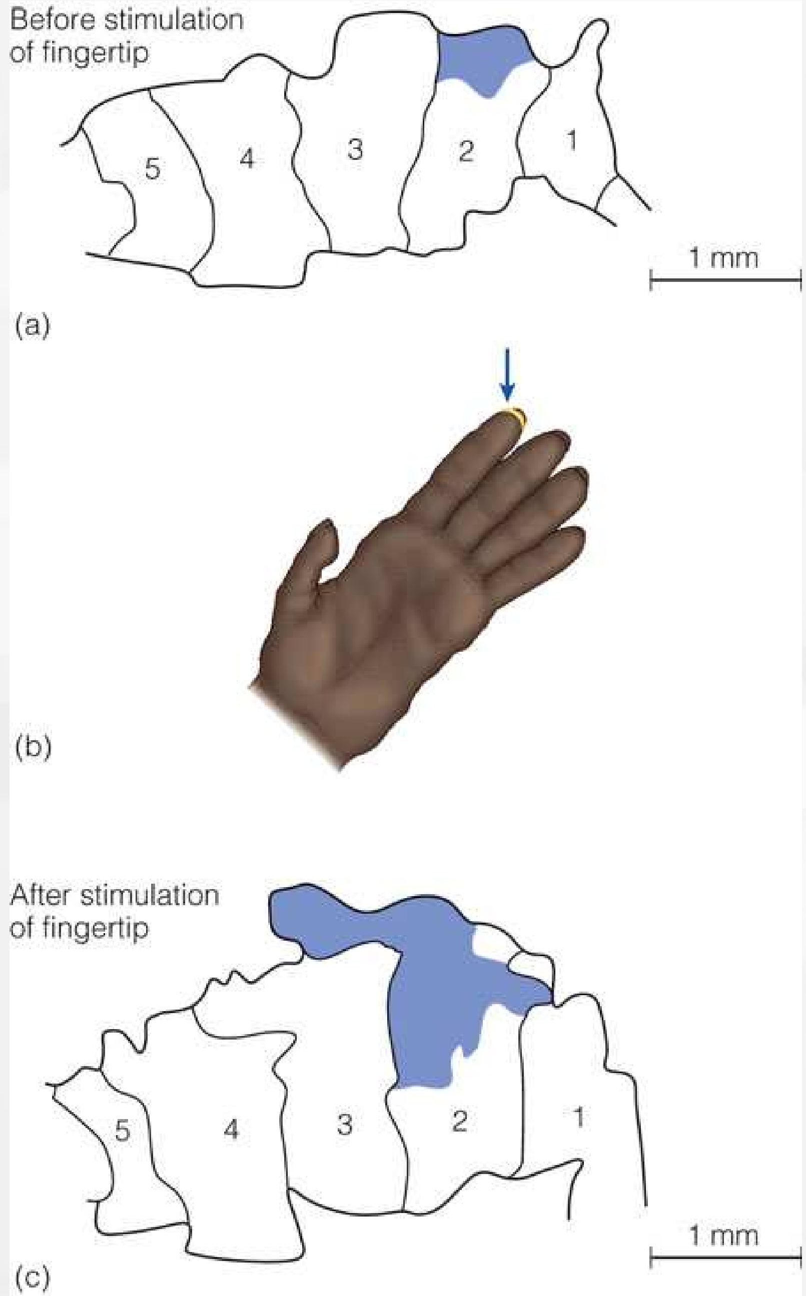
Sure enough, an fMRI experiment in 1999 showed that Ramachandran was right and the somatosensory homunculus shown in textbooks (and Penfield) is wrong.

Phantom Limb Disorder

Phantom limb disorder can be painful and uncomfortable.

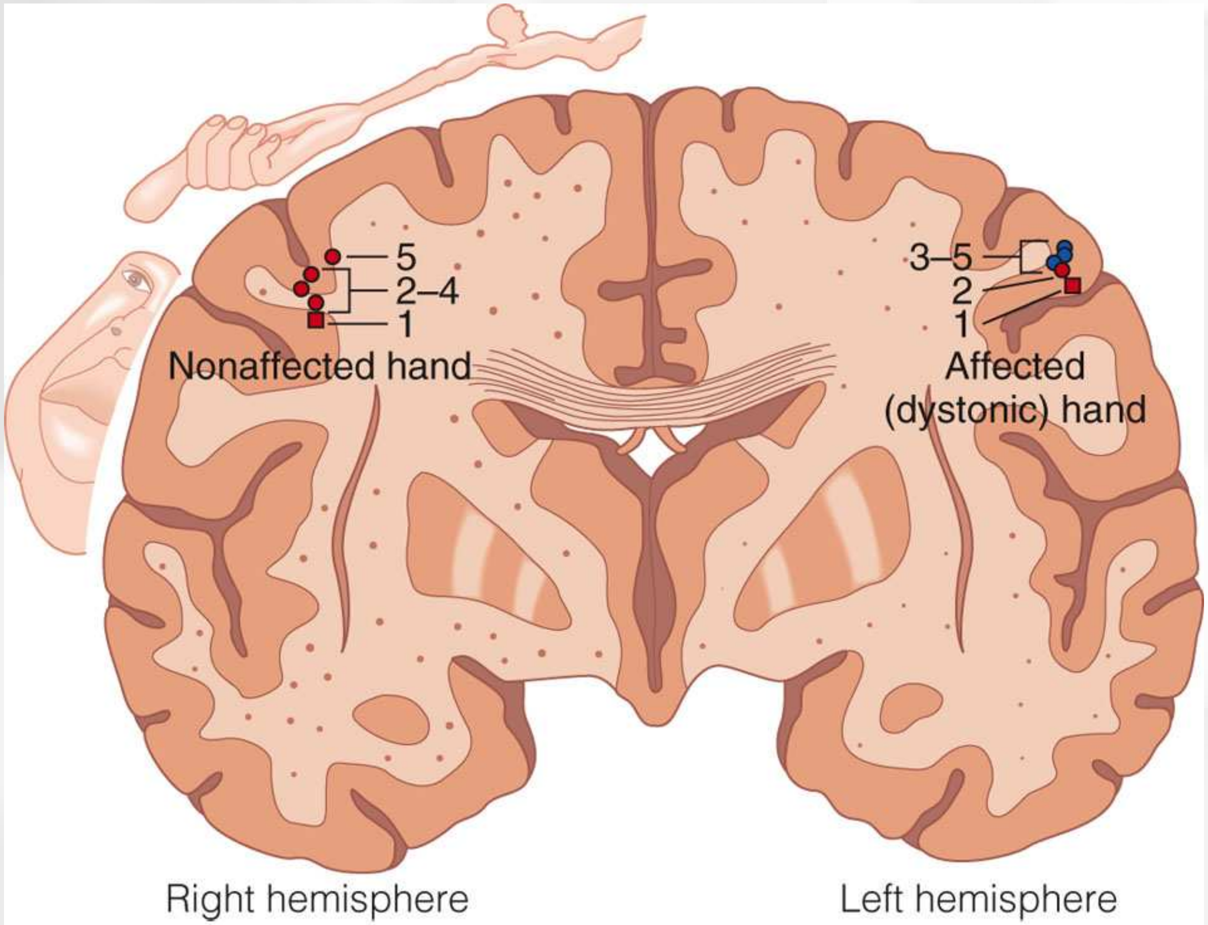
Ramachandran used a ‘mirror box’ to simulate the presence of the amputated hand which alleviated the symptoms in most of his patients.

Plasticity in neural functioning leads to multiple homunculi and changes in how cortical cells are allocated to body parts



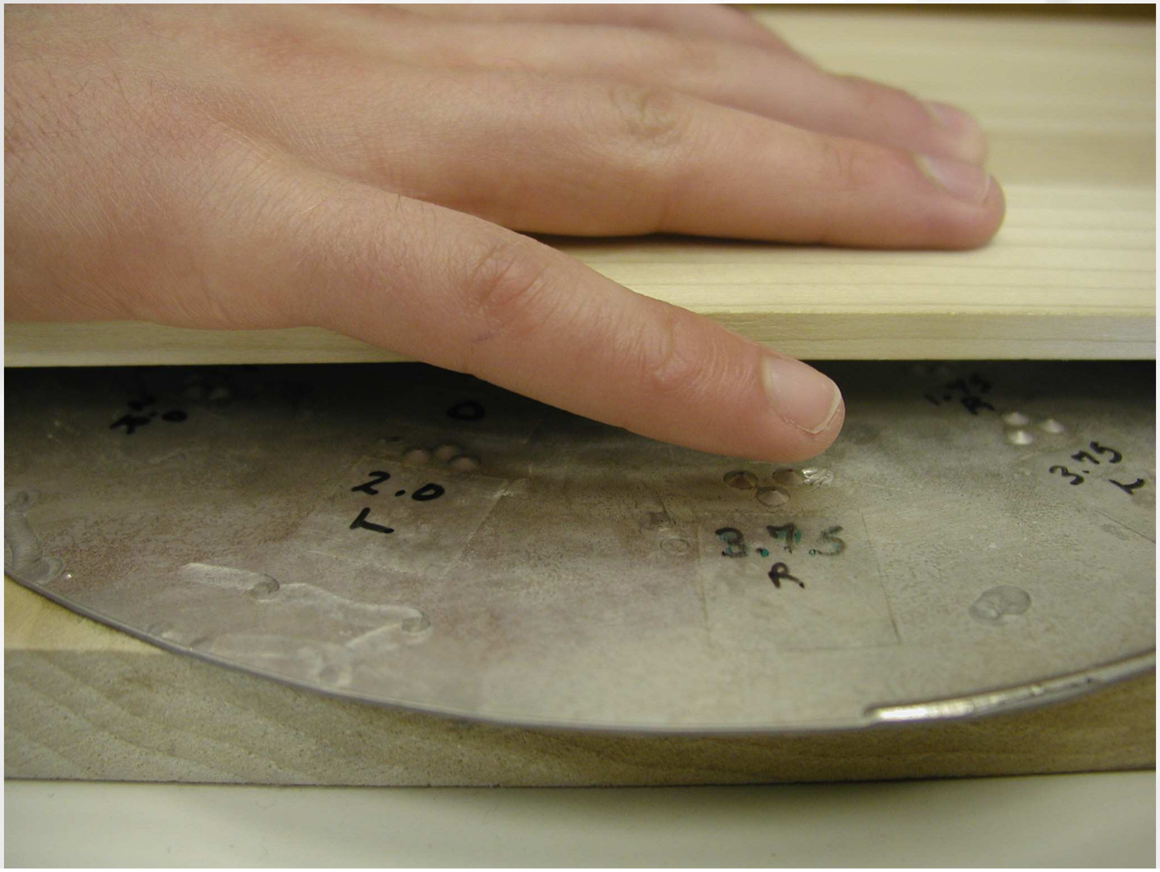
Maps of the Body on the Cortex

- 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
  - Fortunately (??) this only happens in about 1% of musicians

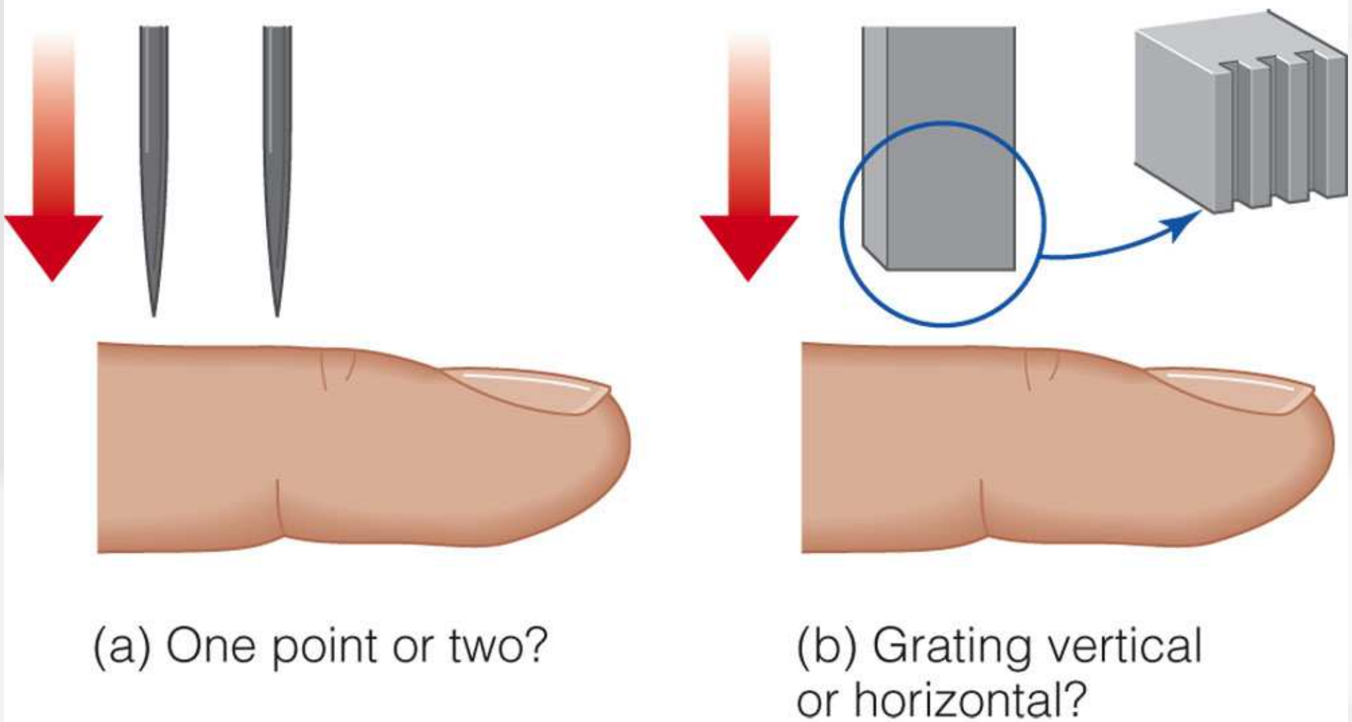


Perceiving Details

- Measuring tactile acuity
  - Two-point threshold - minimum separation needed between two points to perceive them as two units
  - Grating acuity - placing a grooved stimulus on the skin and asking the participant to indicate the orientation of the grating

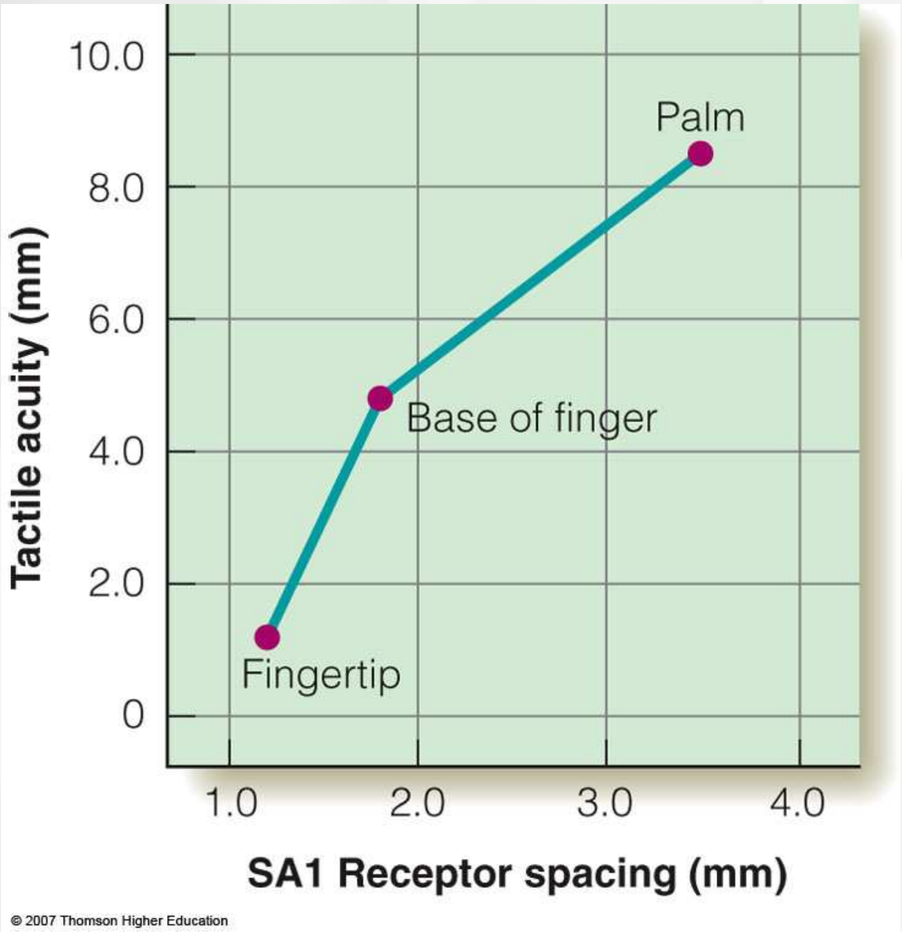


Tactile acuity thresholds are determined by Merkel receptors (SA1)



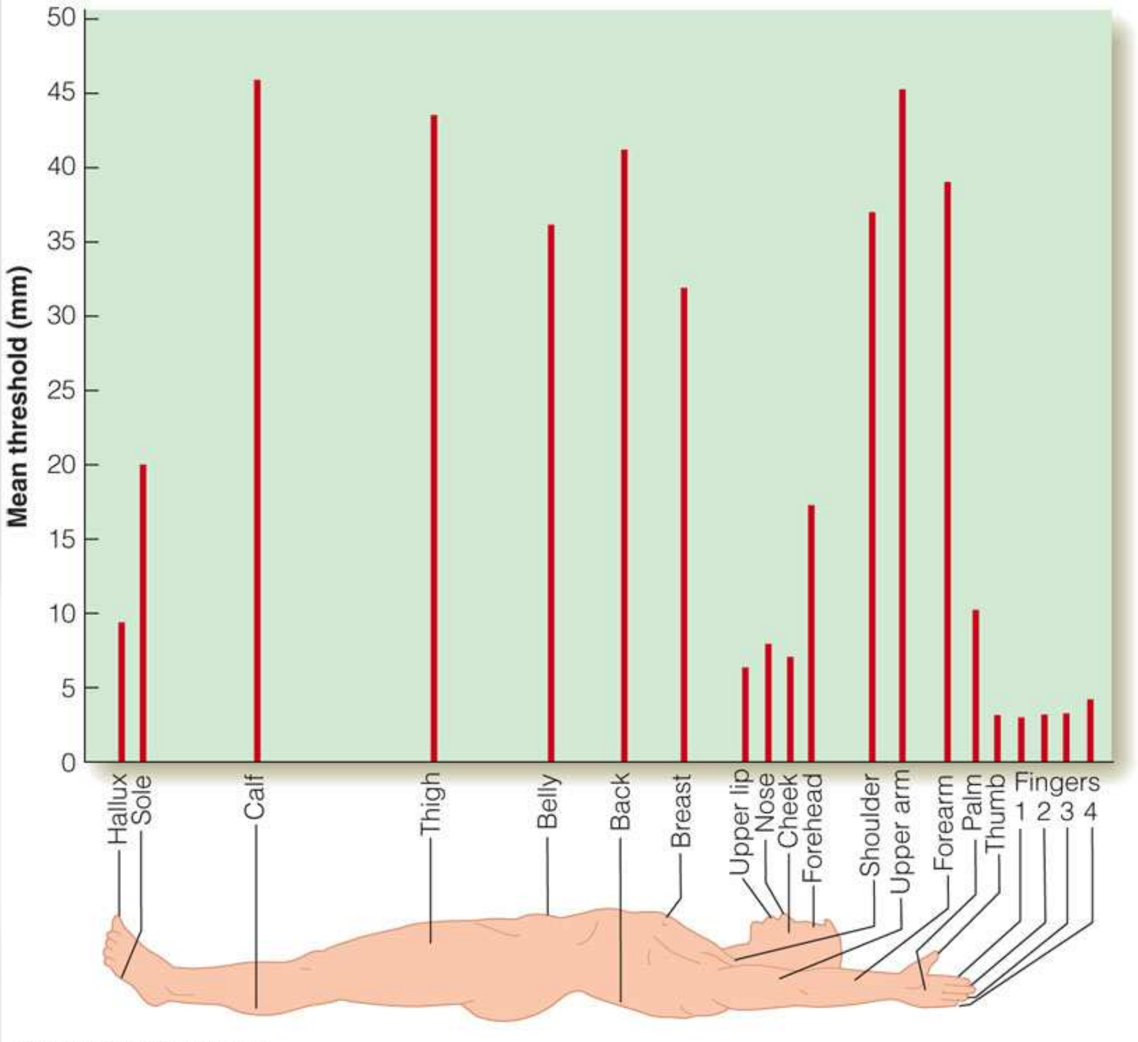
Receptor Mechanisms for Tactile Acuity

- There is a high density of Merkel receptor/SA1 fibers in the fingertips
- Merkel receptors are densely packed on the fingertips - similar to cones in the fovea
- Both two-point thresholds and grating acuity studies show these results



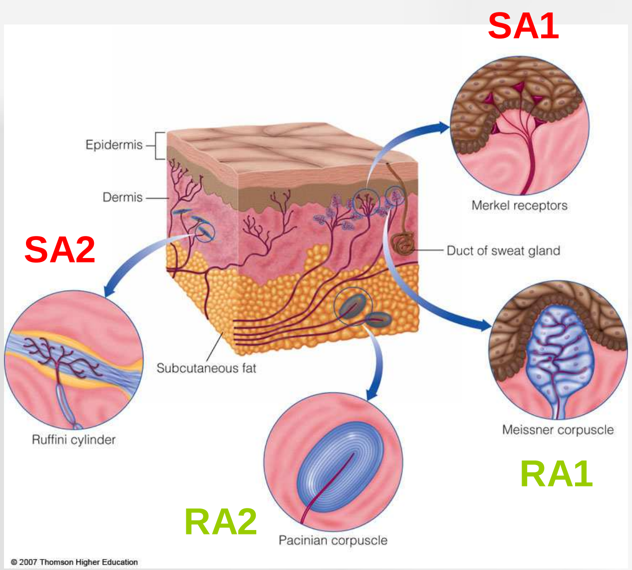
Cortical Mechanisms for Tactile Acuity

- Body areas with high acuity have larger areas of cortical tissue devoted to them
- This parallels the “magnification factor” seen in the visual cortex for the cones in the fovea



Receptive field sizes correlate with tactile spatial acuity.

Recall from yesterday:



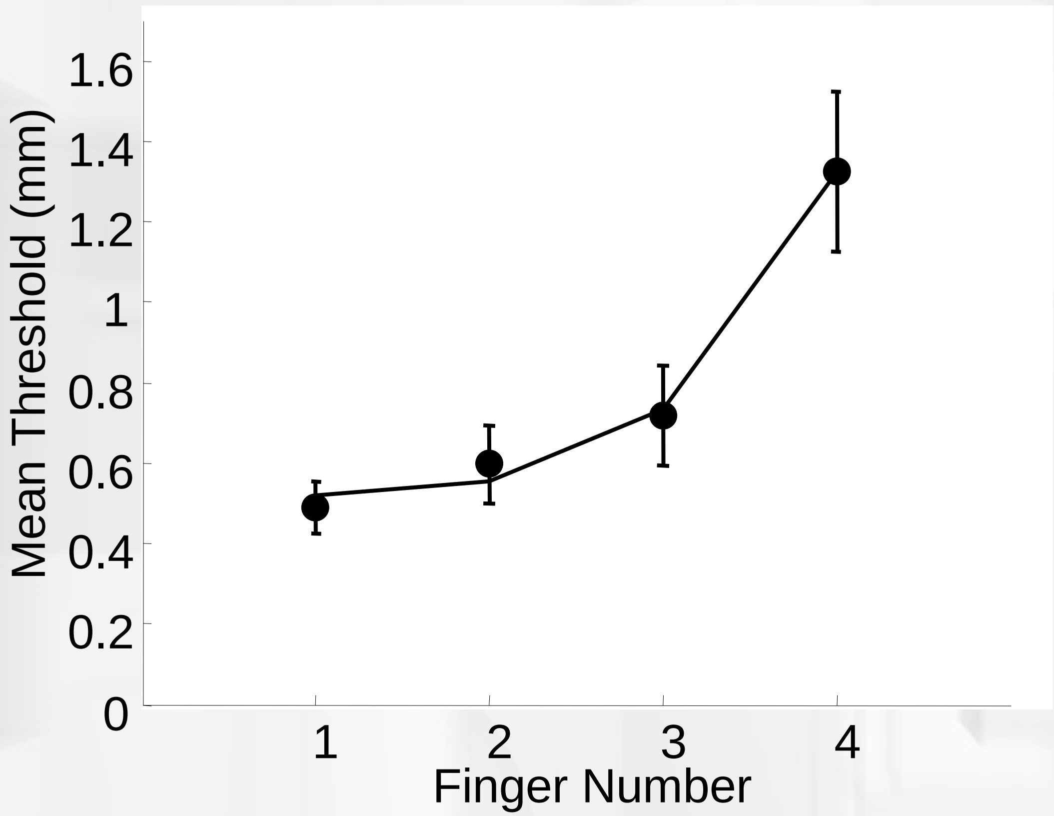
Surface receptors: Merkel receptors (SA1) and Meissner receptors (RA1) have small receptive fields and respond to slow vibration rates.

Deep receptors: RA2 fibers (Pacinian corpuscle) and Ruffini (SA2) have large receptive fields and respond to high vibration rates.

Adapting Rate

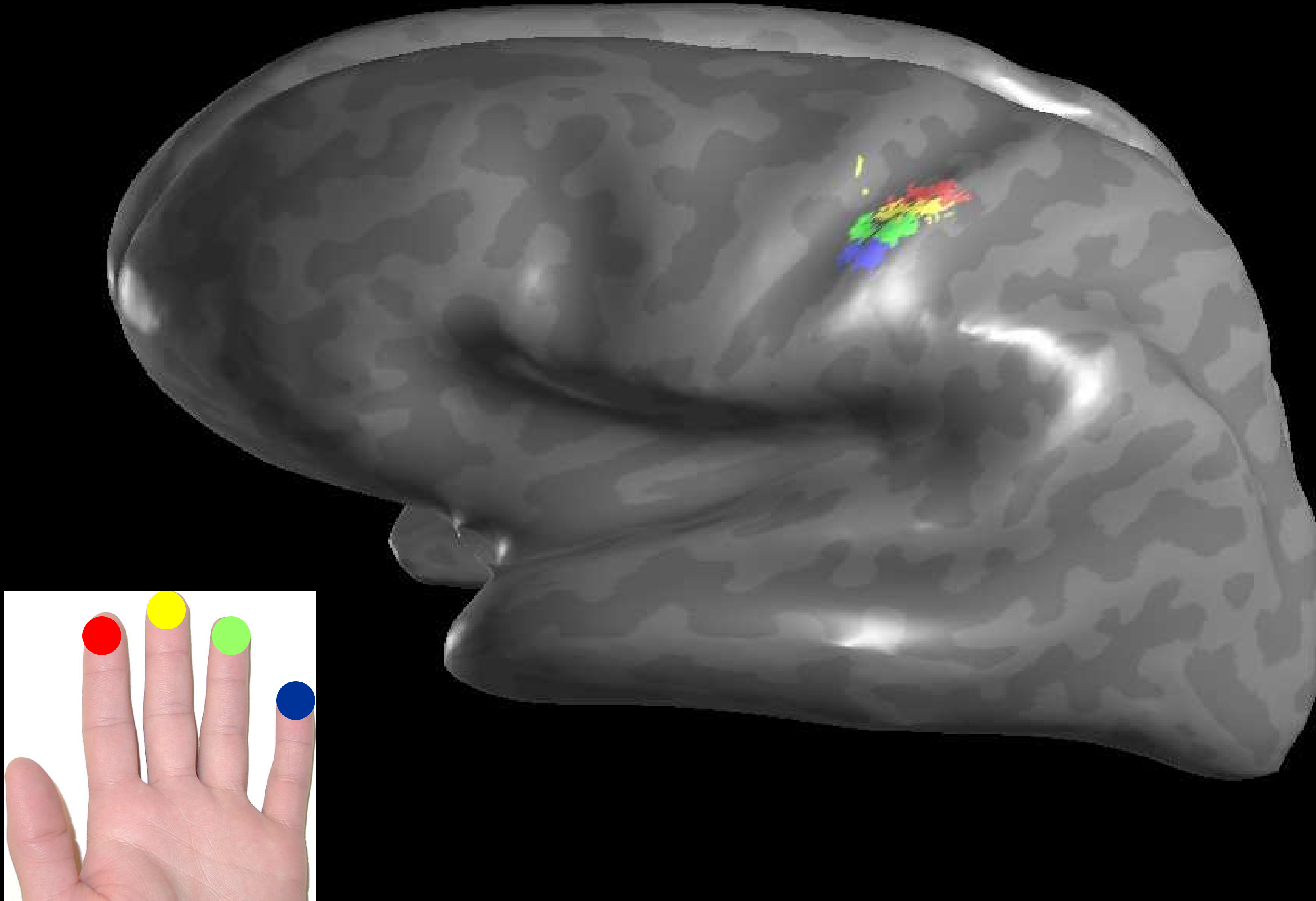
Vibration frequency	Slow	Rapid
Low	**Merkel receptors (SA1)**	Meissner receptors (RA1)
High	Ruffini (SA2)	**Pacinian corpuscle (RA2)**

Acuity decreases (thresholds increase) from the index to the pinky, but the density of Merkel receptors is the same across the fingers.



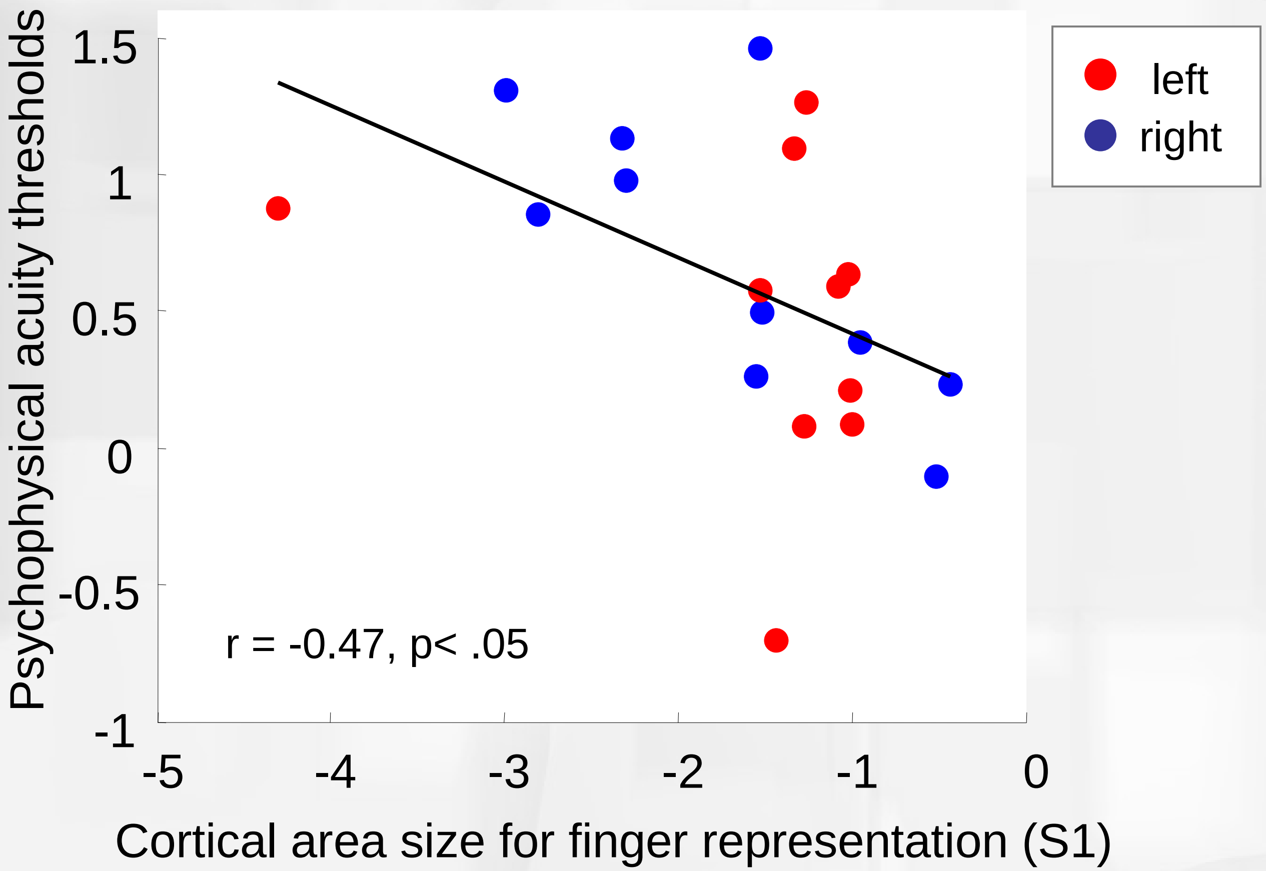
But there is a larger representation of the index finger in S1.

S1, not the Merkel receptors, seem to be the limiting factor in tactile acuity.



(Duncan and Boynton, 2007)

Subjects with better (lower) acuity thresholds have larger representations of the fingers in S1



(Duncan and Boynton, 2007)

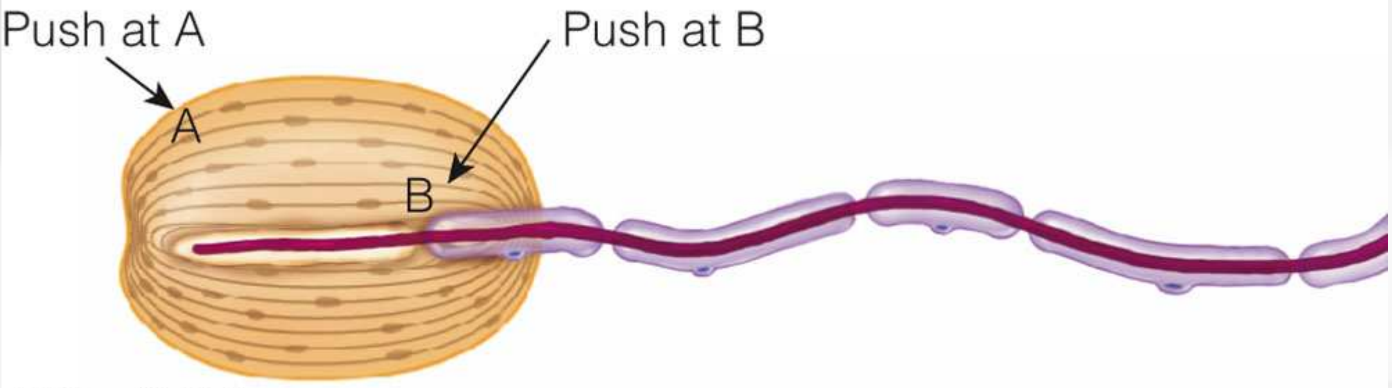
Perceiving Vibration

In the 60's, Werner Lowenstein stimulated the pacinian corpuscle itself (location A), and also after dissecting it so that he could stimulate near the nerve fiber.

Mechanical stimulation at location A caused the usual rapid adapting response.

Mechanical stimulation at location B did not produce rapid adaption; reponse continued during the entire period of stimulation.

So, the onion-like structure of the pacinan corpuscle must be responsible for the rapid adaptation.

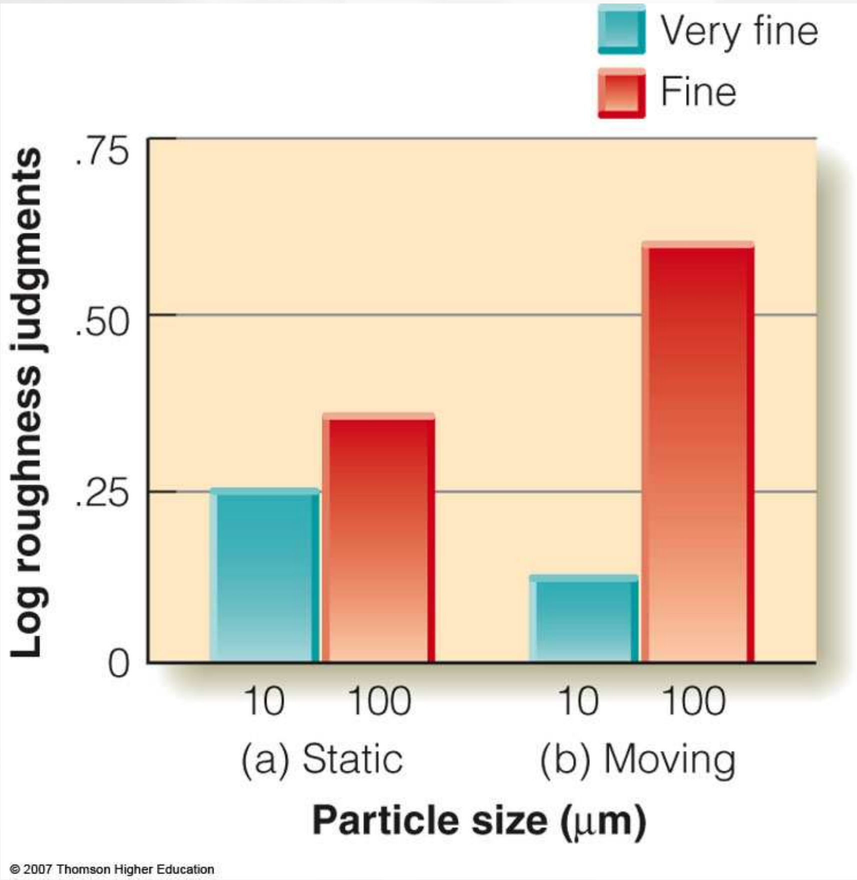


Perceiving Texture

- 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
- Two receptors may be responsible for this process - called the *duplex theory of texture perception*

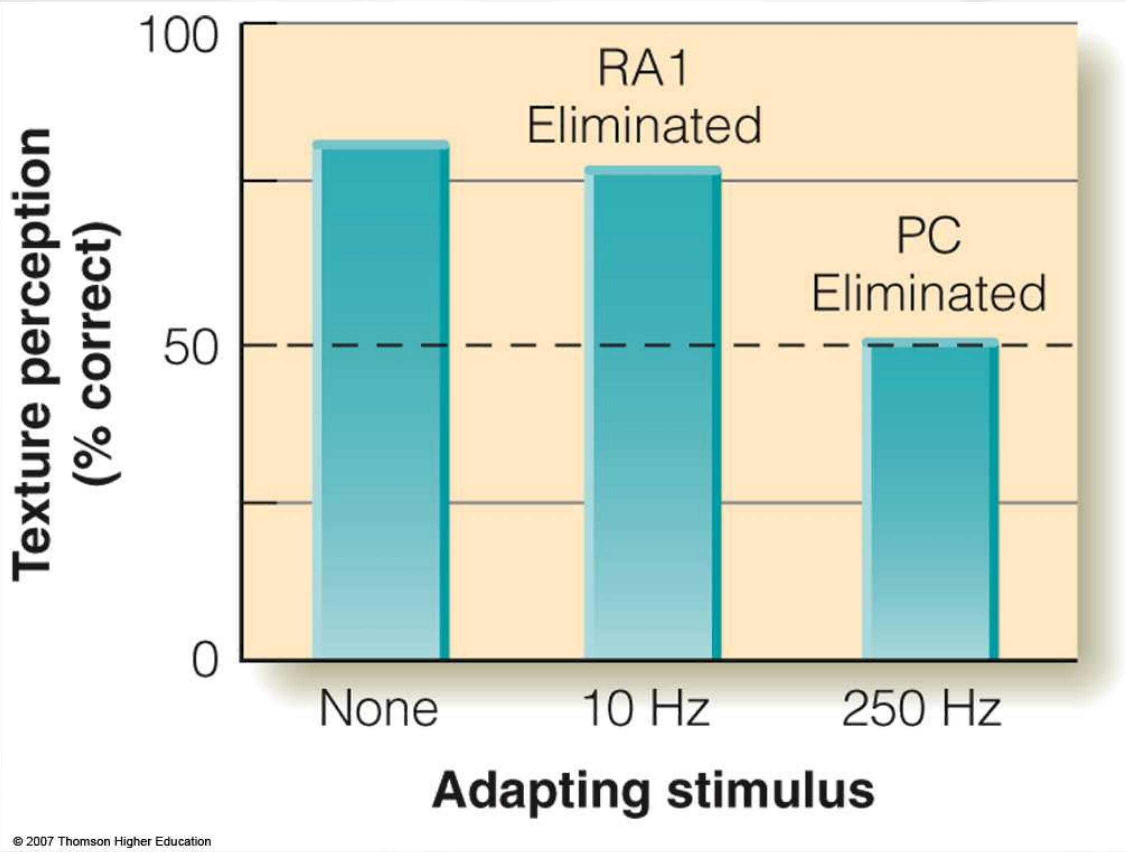
Perceiving Texture

- Past research 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



Adaptation Experiment by Hollins et al.

- Participants' skin was adapted with either:
  - 10-Hz stimulus for 6 minutes to adapt the RA1/Meissner corpuscle
  - 250-Hz stimulus for 6 minutes to adapt the RA2/Pacinian corpuscle
- Results showed that only the adaptation to the 250-Hz stimulus affected the discrimination of fine textures.

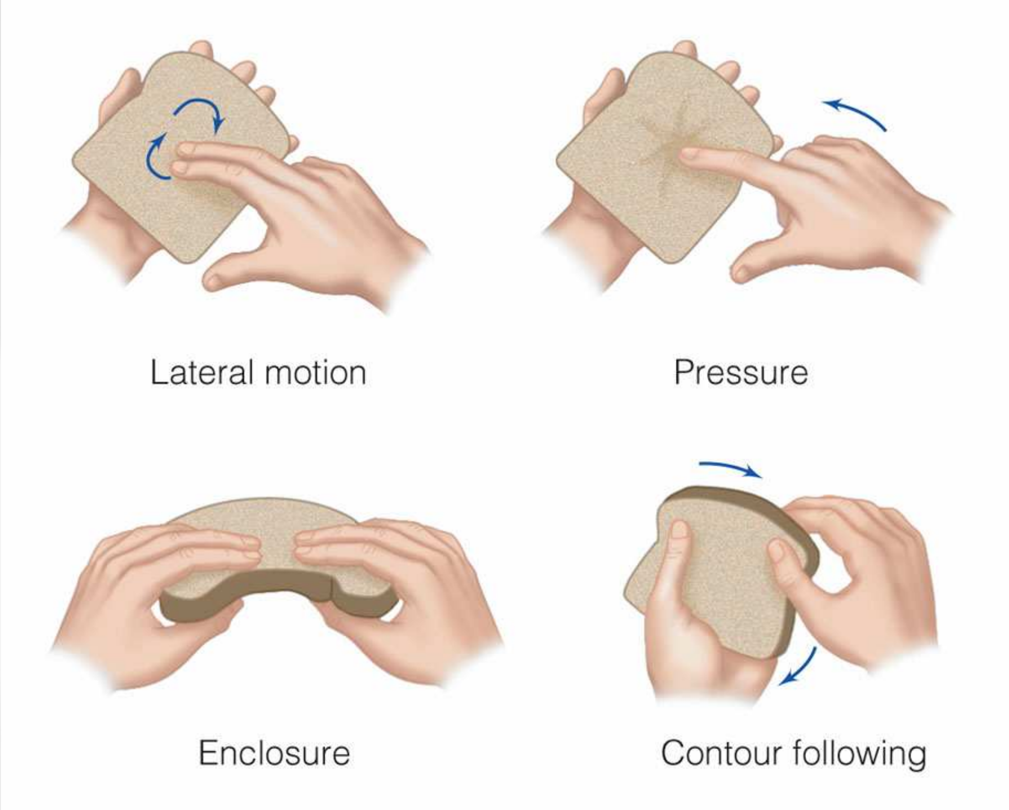


Perceiving Objects

- Humans use active rather than passive touch to interact with the environment
- Haptic perception is the active exploration of 3-D objects with the hand
  - It uses three distinct systems:
    - Sensory system
    - Motor system
    - Cognitive system

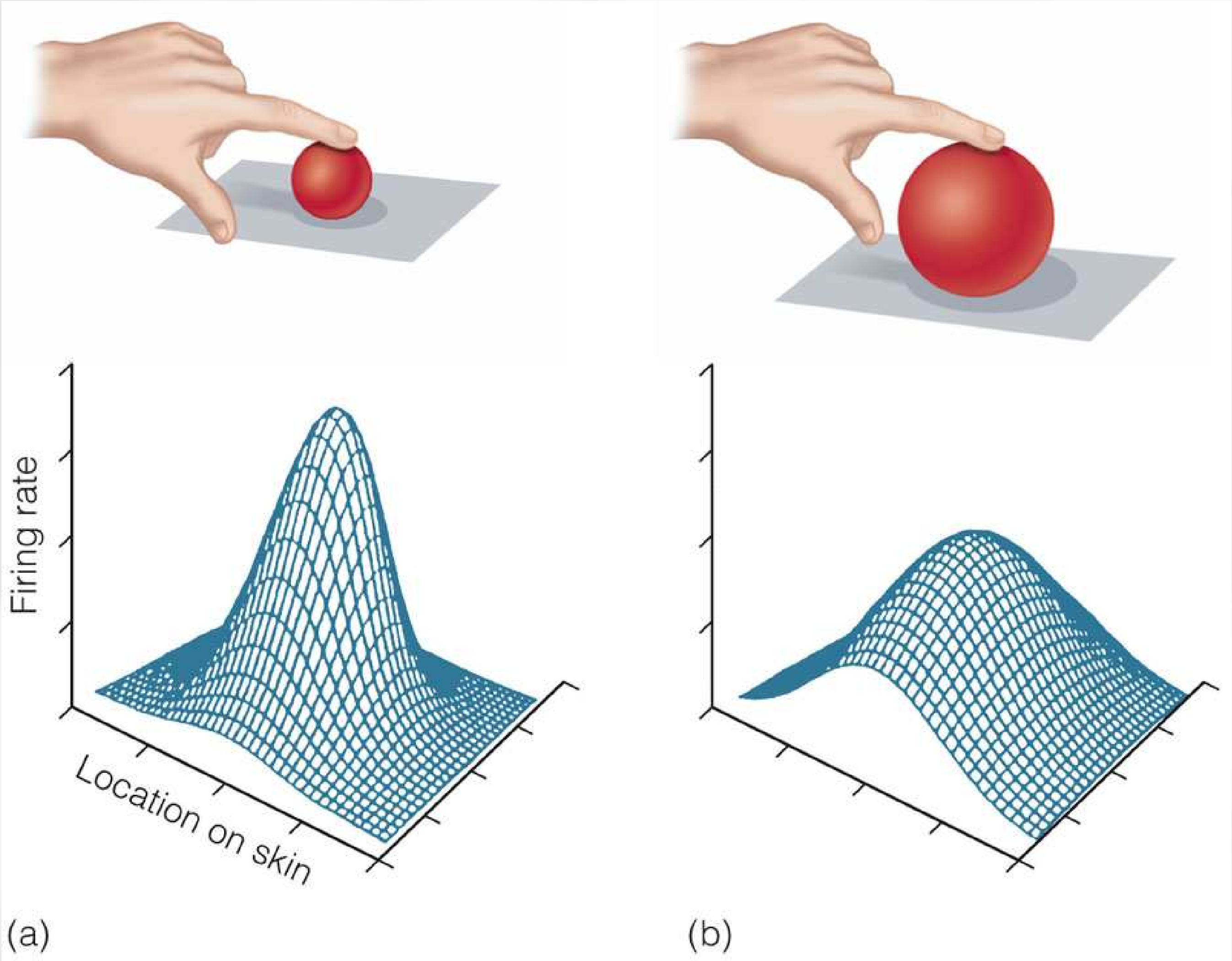
Perceiving Objects

- Psychophysical 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



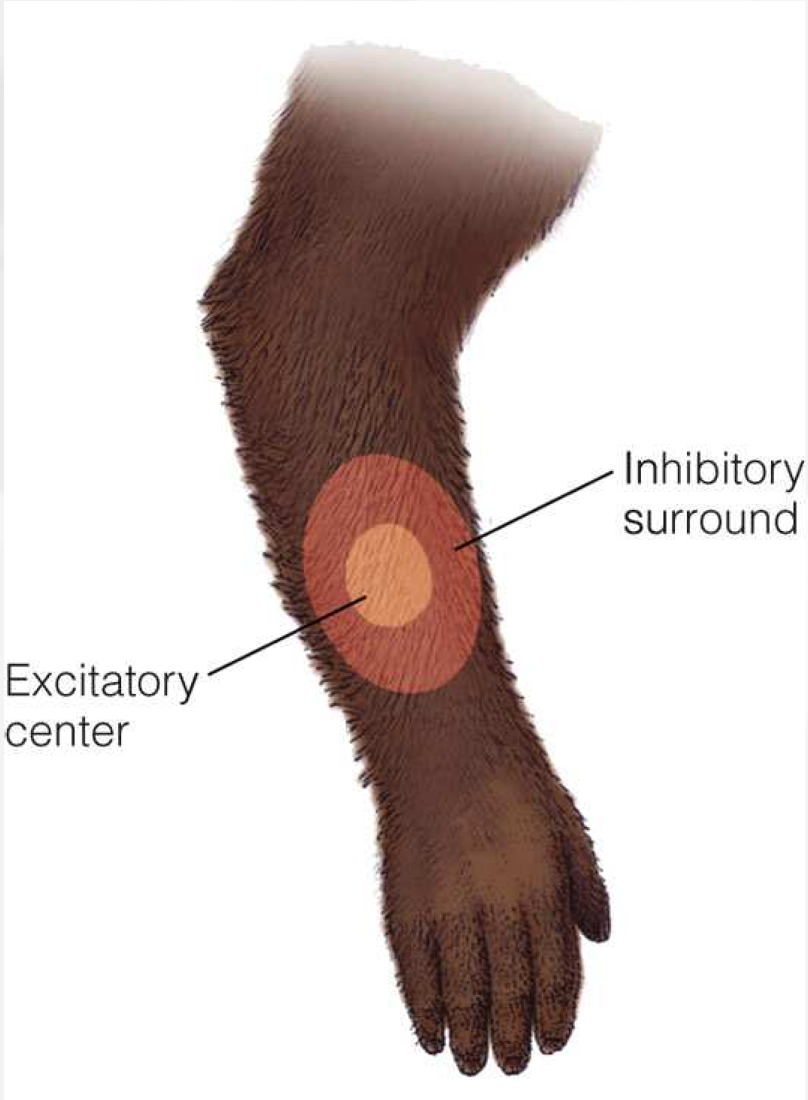
The Physiology of Tactile Object Perception

- The firing pattern of groups of mechanoreceptors signals shape, such as the curvature of an object

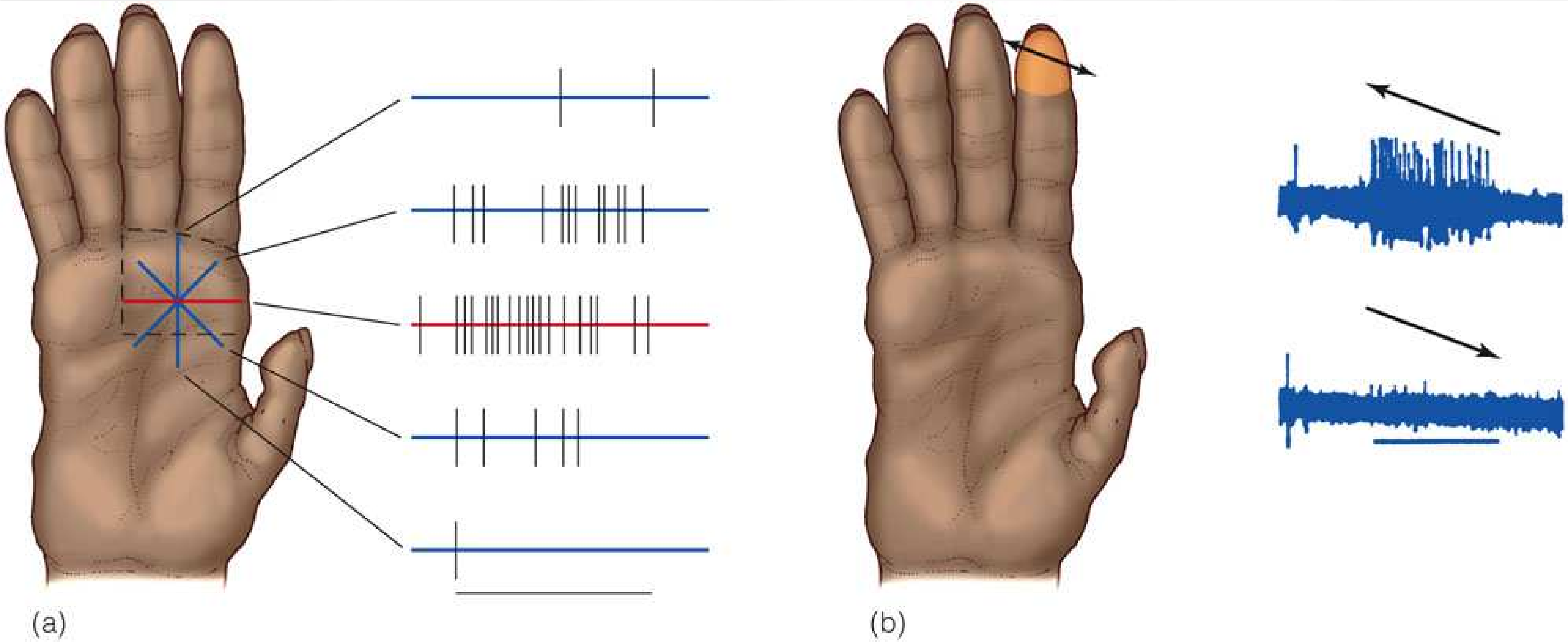


Neurons further upstream become more specialized

Monkey's thalamus shows cells that respond to center-surround receptive fields

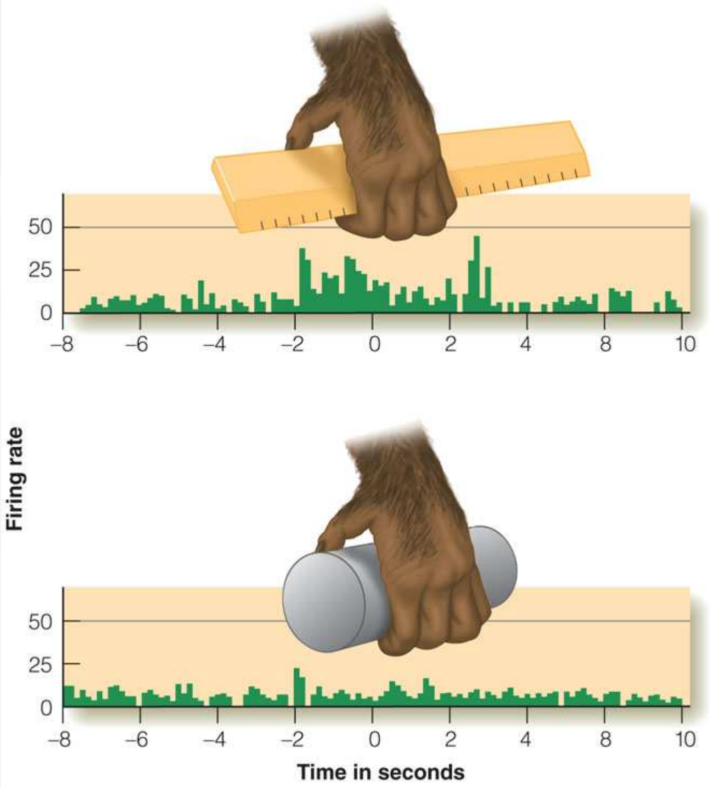


Somatosensory cortex shows cells that respond maximally to orientations and direction of movement

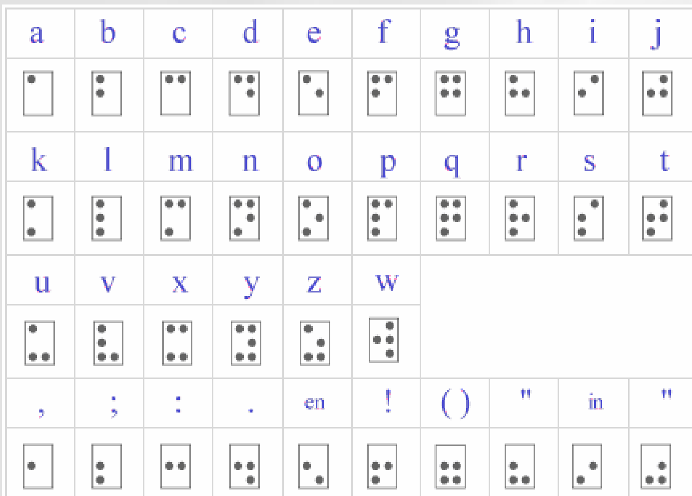


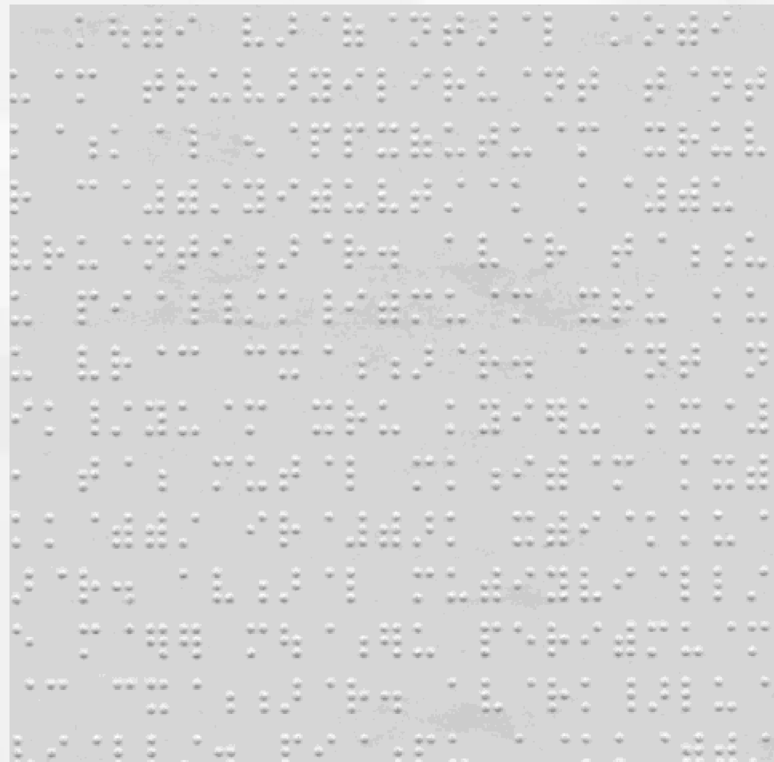
The Physiology of Tactile Object Perception

- Monkey's somatosensory cortex also shows neurons that respond best to:
  - Grasping specific objects
  - Paying attention to the task
    - Neurons may respond to stimulation of the receptors, but attending to the task increases the response



English Braille

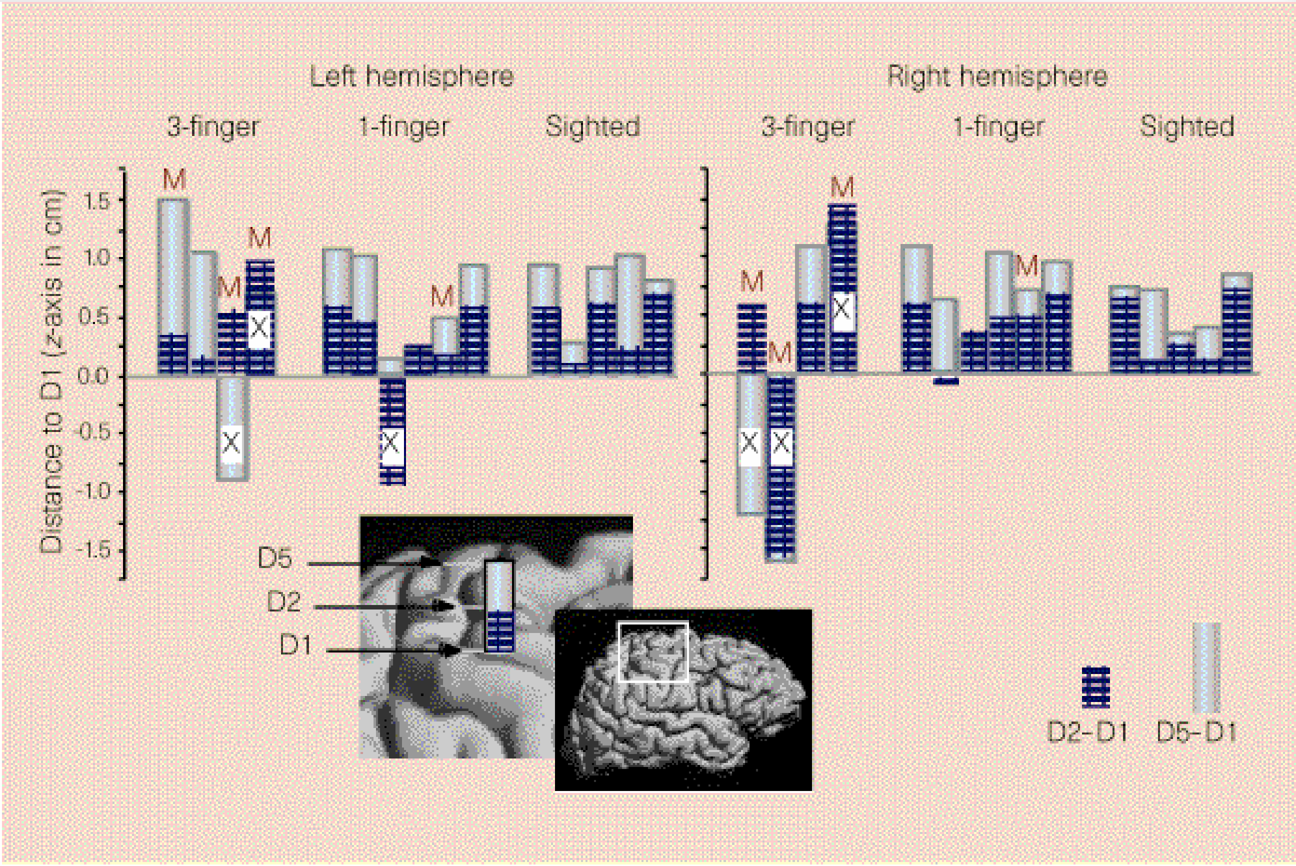




Experienced Braille readers can read about 100 words per minute (as opposed to 250-300 for visual reading)

A blind user can read the screen of his computer with a Braille display or with a speech synthesizer (or both together). He/she moves on the screen in using moving keys either on a specific keyboard or in using the standard keyboard.

Three-finger Braille readers have distorted map for the finger representations in SA1 compared to 1-finger Braille readers and sighted control subjects.



Sterr et al., Nature **391**, 134-135

In addition to the expected responses in somatosensory cortex, experienced Braille readers show large fMRI responses in the occipital cortex while reading Braille compared to control subjects.

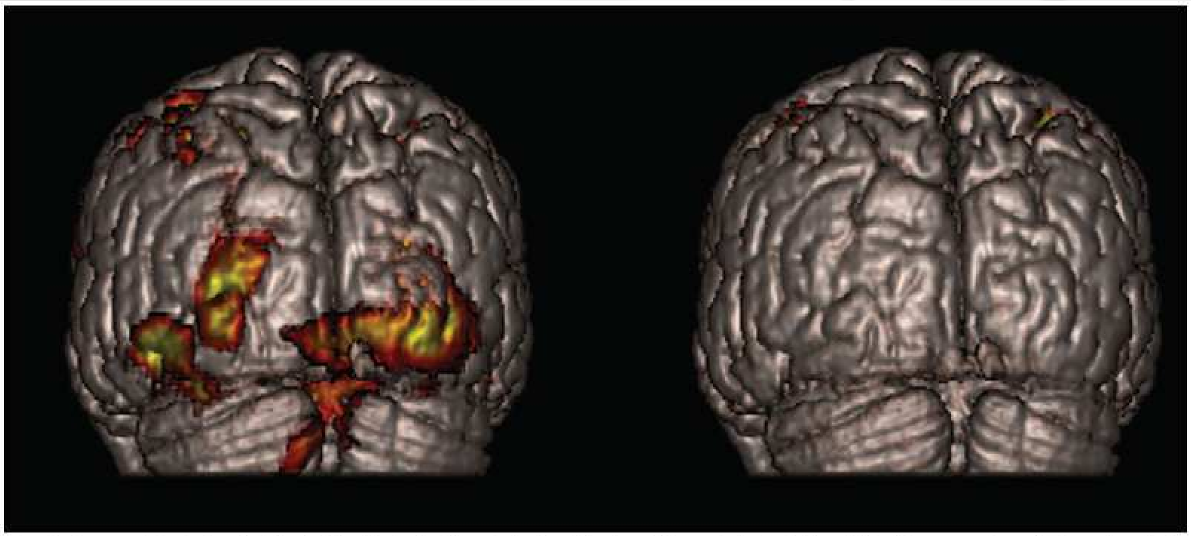
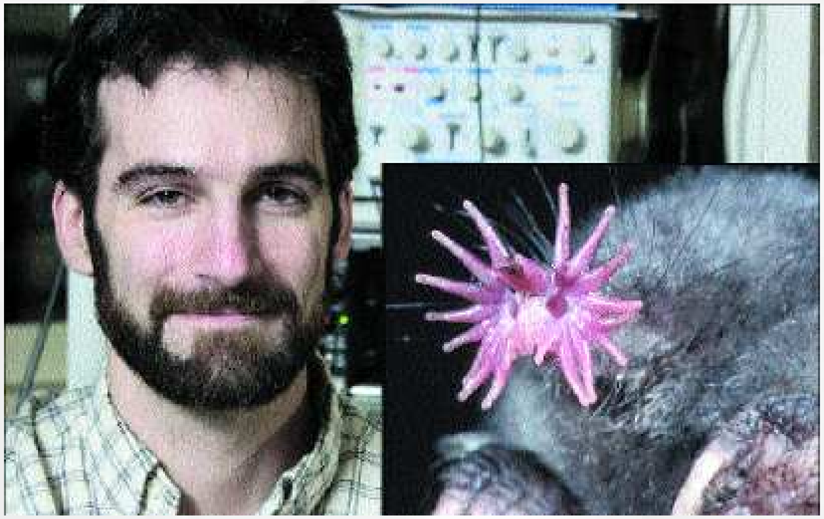


Fig. 2. Areas activated by Braille tactile discrimination tasks in a blind participant who lost his sight at 3 years of age (*left*) and a sighted control (*right*). The brain areas are superimposed on a surface-rendered high-resolution magnetic resonance image viewed from behind. In the blind subject, activity was seen in the occipital lobe, which includes the V1. By contrast, no activation of the occipital lobe was seen in the sighted subject.

Sadato, N. *Neuroscientist*. 2005;11(6):577-82.

The champion of somatosensory perception: the ***Star Nosed Mole***



Ken Catania at Vanderbilt has made a career studying this animal.

During normal foraging activity, the tentacles are constantly being used to feel the mole's surroundings, moving so rapidly that they appear as a blur of motion, touching as many as 12 objects per second. Using these supersensitive organs, identification of prey can be made in under half a second.

Pain Perception

Copied from comments by Ronald Melzack:

Descartes' specifity theory proposed that injury activates specific pain receptors and fibers which, in turn, project pain impulses through a spinal pain pathway to a pain center in the brain.

The psychological experience of pain, therefore, was virtually equated with peripheral injury.

In the 1950's, there was no room for psychological contributions to pain, such as attention, past experience and the meaning of the situation. Instead, pain experience was held to be proportional to peripheral injury or pathology.

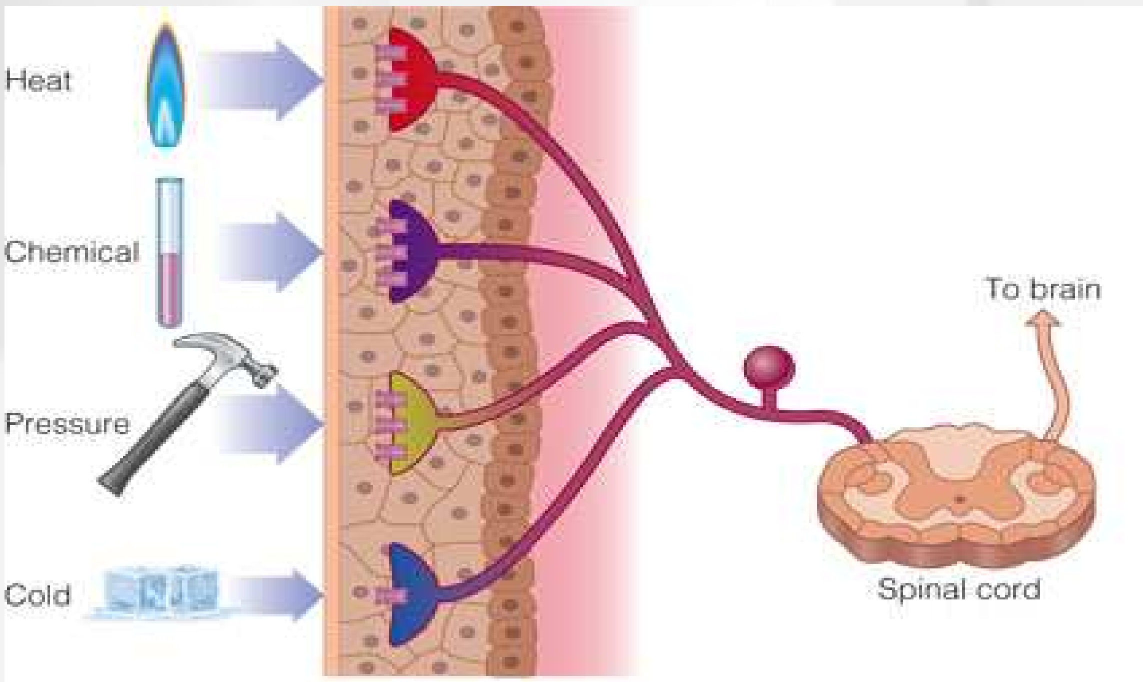
Patients who suffered back pain without presenting signs of organic disease were labelled as "crocks" and sent to psychiatrists. The picture, in short, was simple, and not surprisingly, erroneous.

To thoughtful clinical observers, however, the theory was clearly wrong.

Pain Perception: three kinds

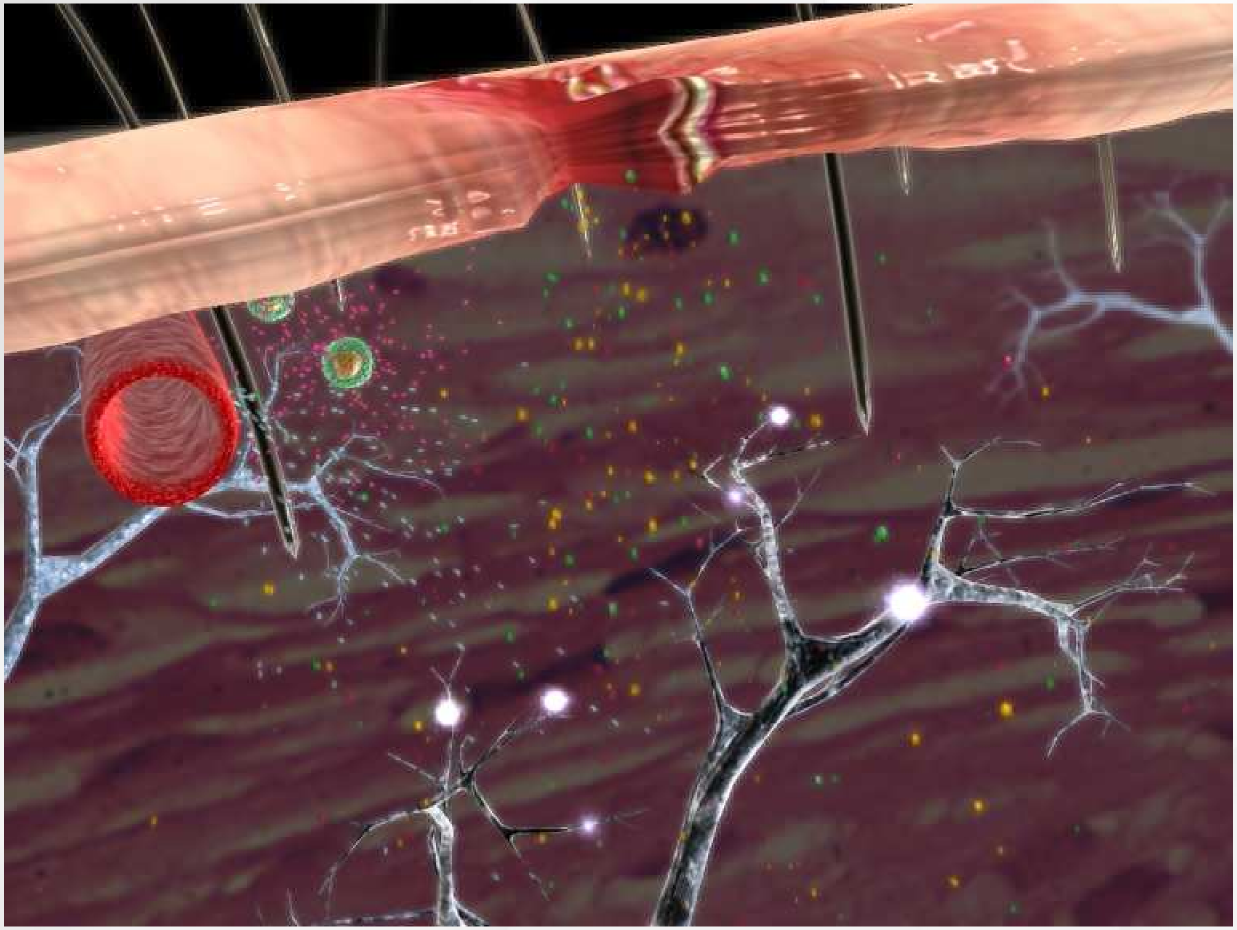
(a) Nociceptive - signals impending damage to the skin

- Types of nociceptors respond to heat, chemicals, severe pressure, and cold
- Threshold of eliciting receptor response must be balanced to warn of damage but not be affected by normal activity

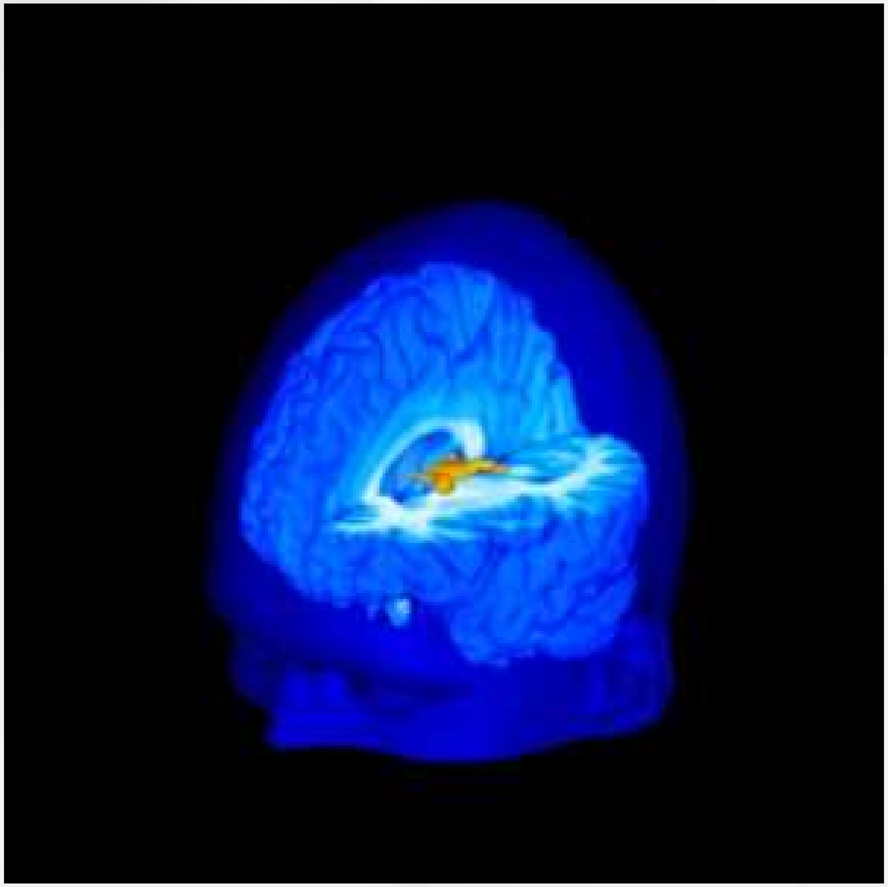


Types of Pain

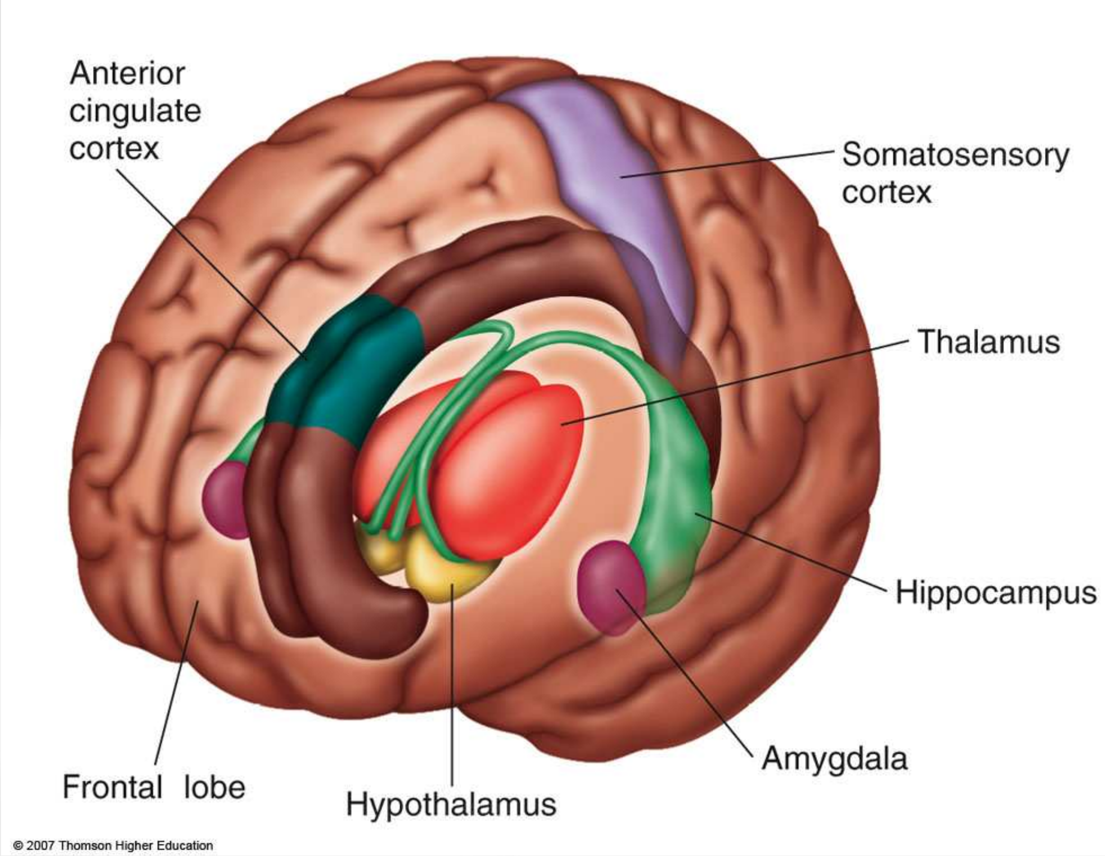
(b) Inflammatory pain - caused by damage to tissues and joints that releases chemicals that activate nociceptors



(c) Neuropathic pain - caused by damage to the central nervous system, such as brain damage caused by stroke, and repetitive movements which cause conditions like carpal tunnel syndrome.



- Signals from nociceptors travel up the spinothalamic pathway and activate:
  - (1) Subcortical areas including the hypothalamus, limbic system, and the thalamus
  - (2) 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*



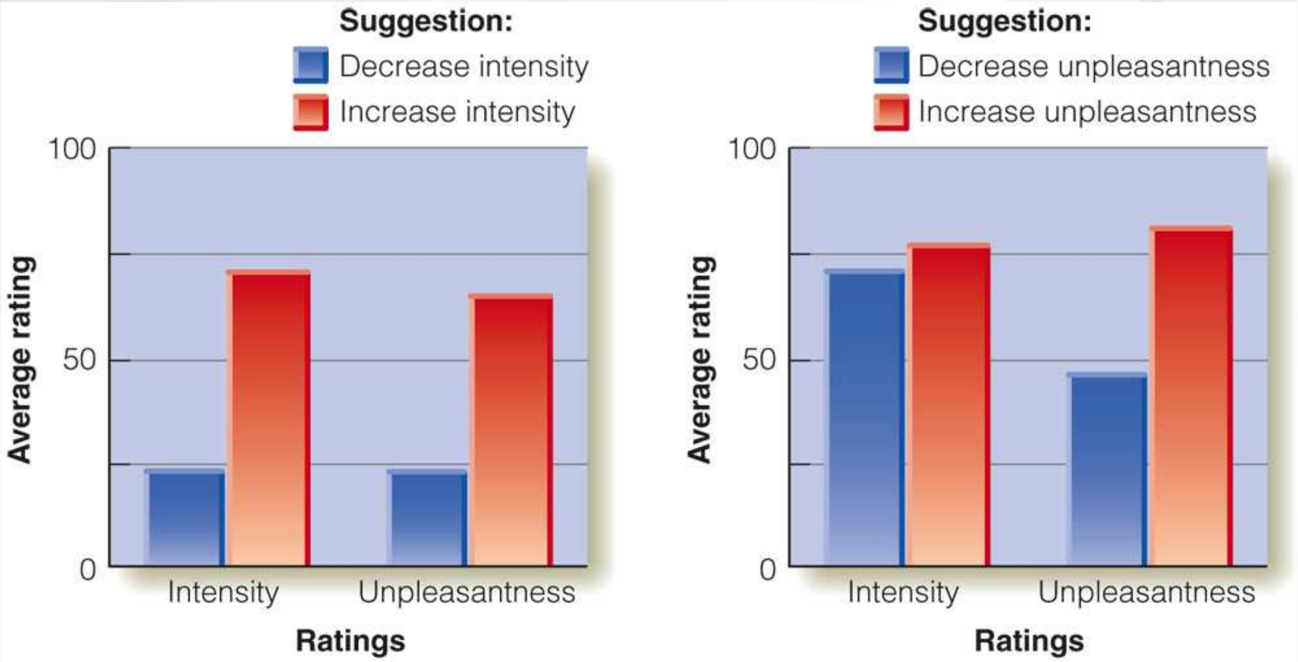
Sensation vs. Perception of pain

Experiment by Hoffauer et al.

- Participants were presented with potentially painful stimuli and asked:
  - To rate subjective pain intensity (sensation)
  - To rate the unpleasantness of the pain (perception)
- Brain activity was measured using PET scanning while they placed their hands into hot water
- Hypnosis was used to increase or decrease the sensory and affective components

Sensation vs. Perception of pain

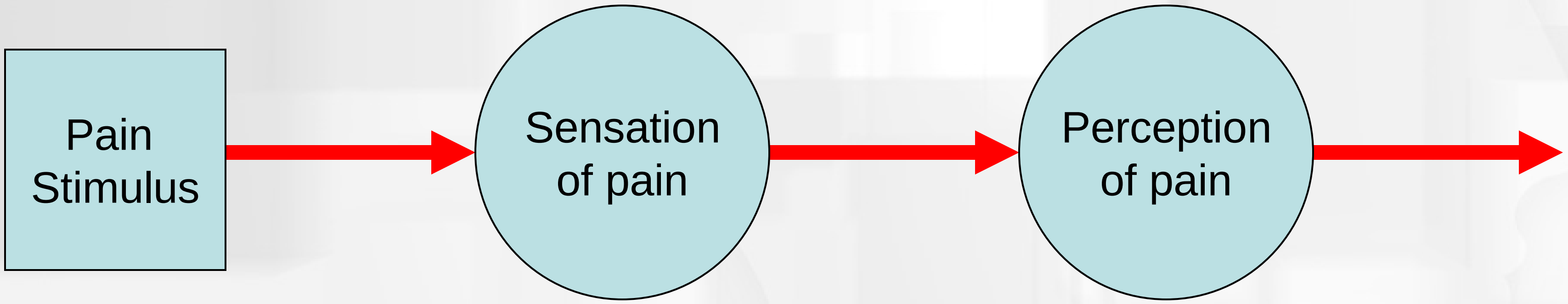
- Results showed that:
  - Suggestions to change the subjective intensity (sensation) led to changes in those ratings and in S1
  - Suggestions to change the unpleasantness of pain (perception) did not affect the subjective ratings (sensation) but did change:
    - Ratings of unpleasantness
    - Activation in the anterior cingulate cortex



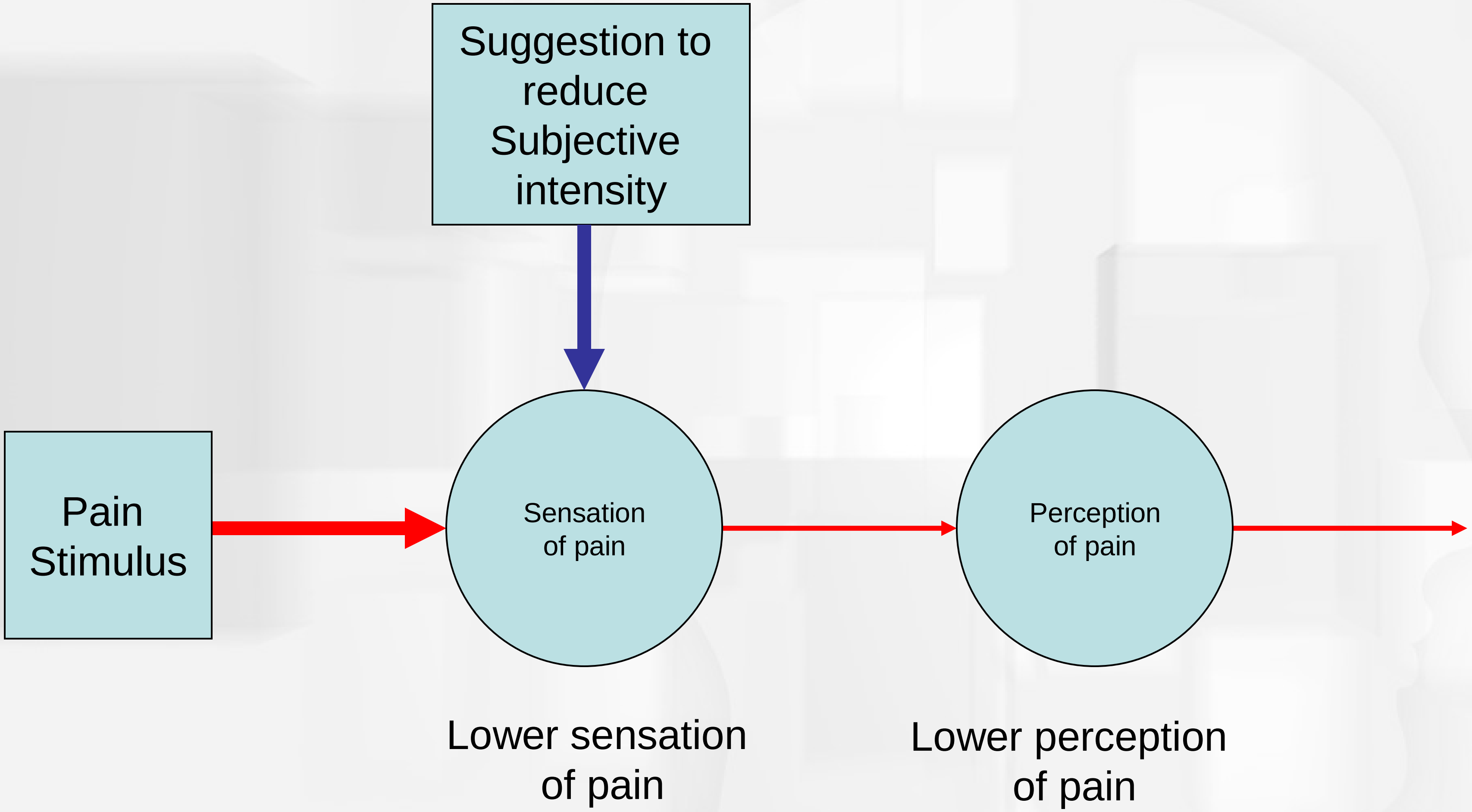
(a) Hypnotic suggestion: change *intensity* of pain

(b) Hypnotic suggestion: change *unpleasantness* of pain

Sensation vs. Perception of pain

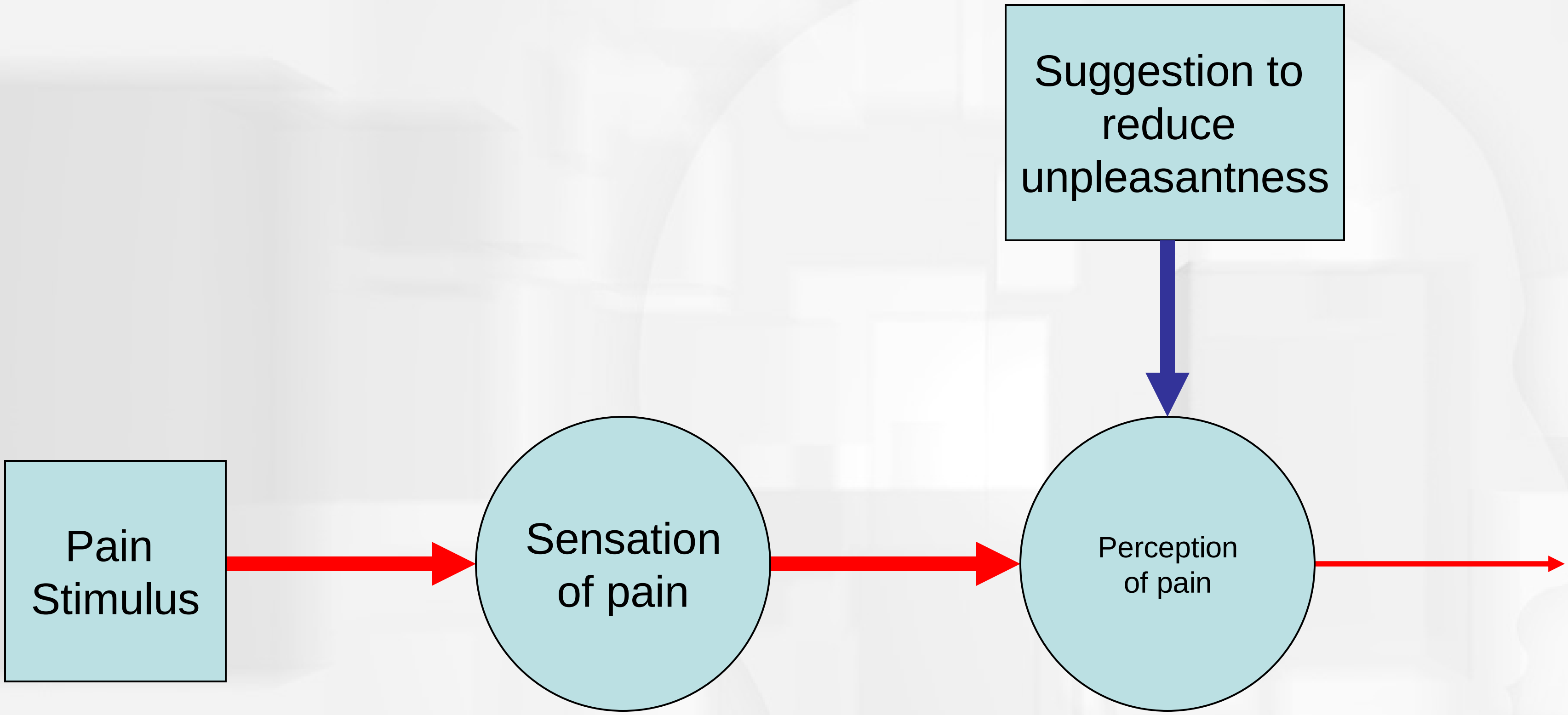


Sensation vs. Perception of pain



Reduced response in S1

Sensation vs. Perception of pain

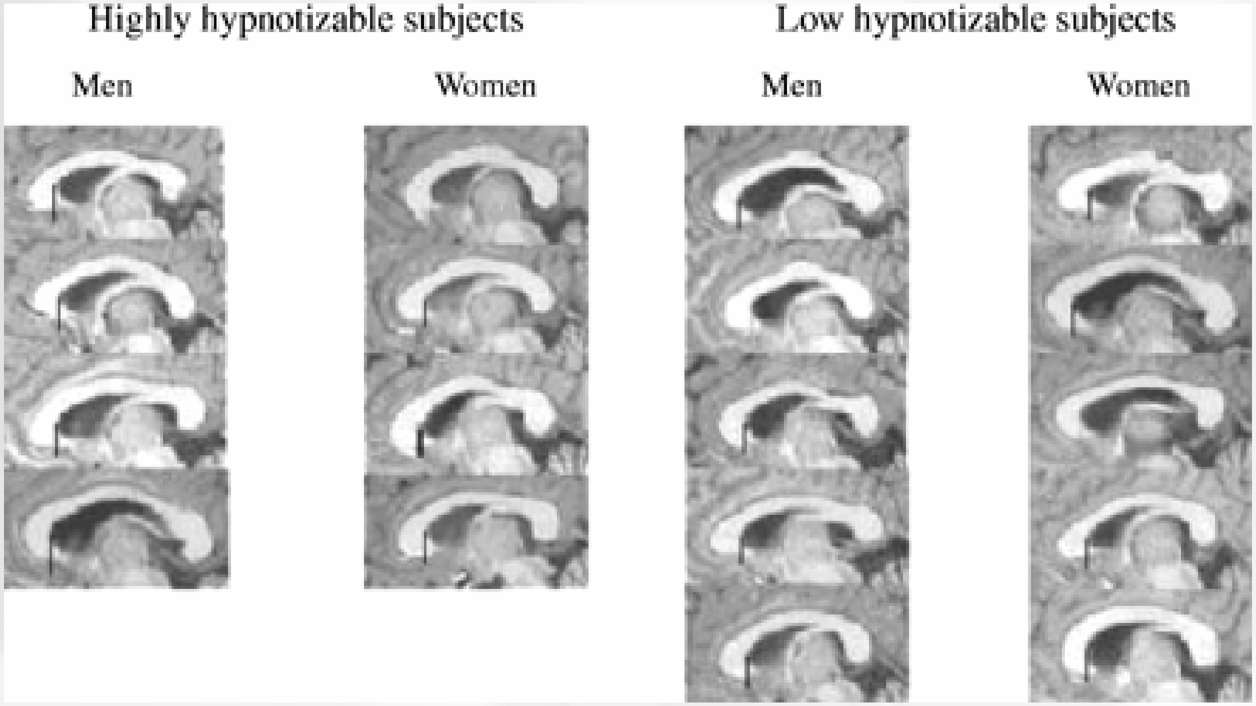


Lower perception of pain

Reduced response in anterior cingulate

Pain and Hypnosis

Increased anterior corpus callosum size is associated positively with hypnotizability and the ability to control pain

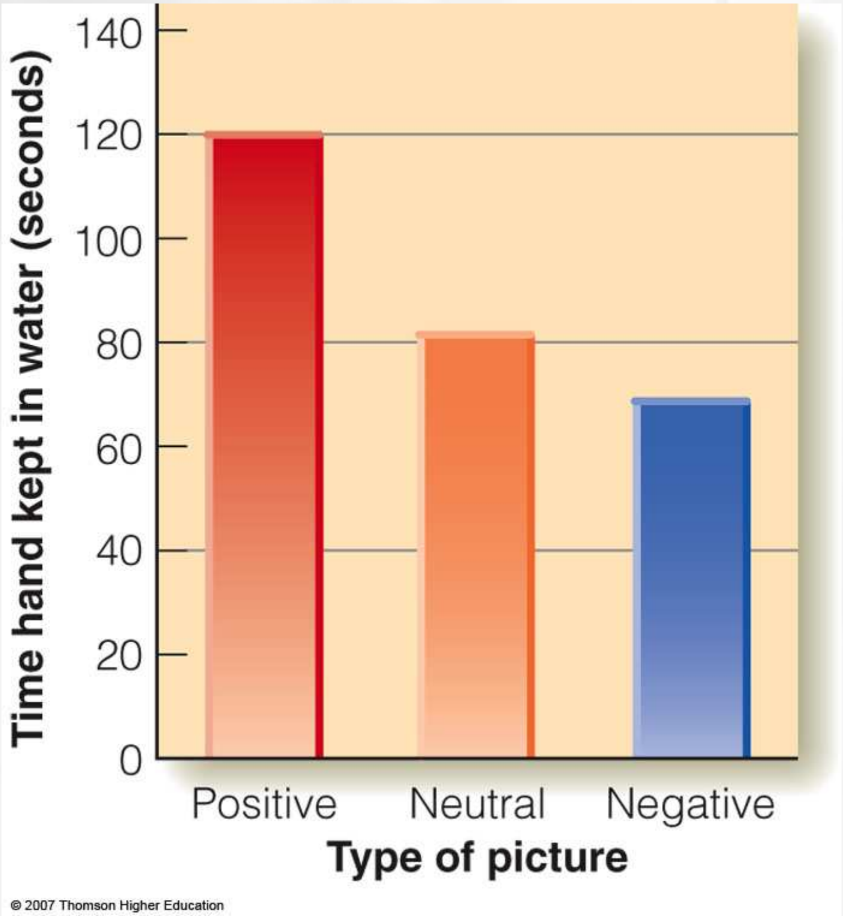


These results suggest that highly hypnotizable subjects have more effective frontal attentional systems implementing control, monitoring performance and inhibiting unwanted stimuli from conscious awareness than low hypnotizable subjects.

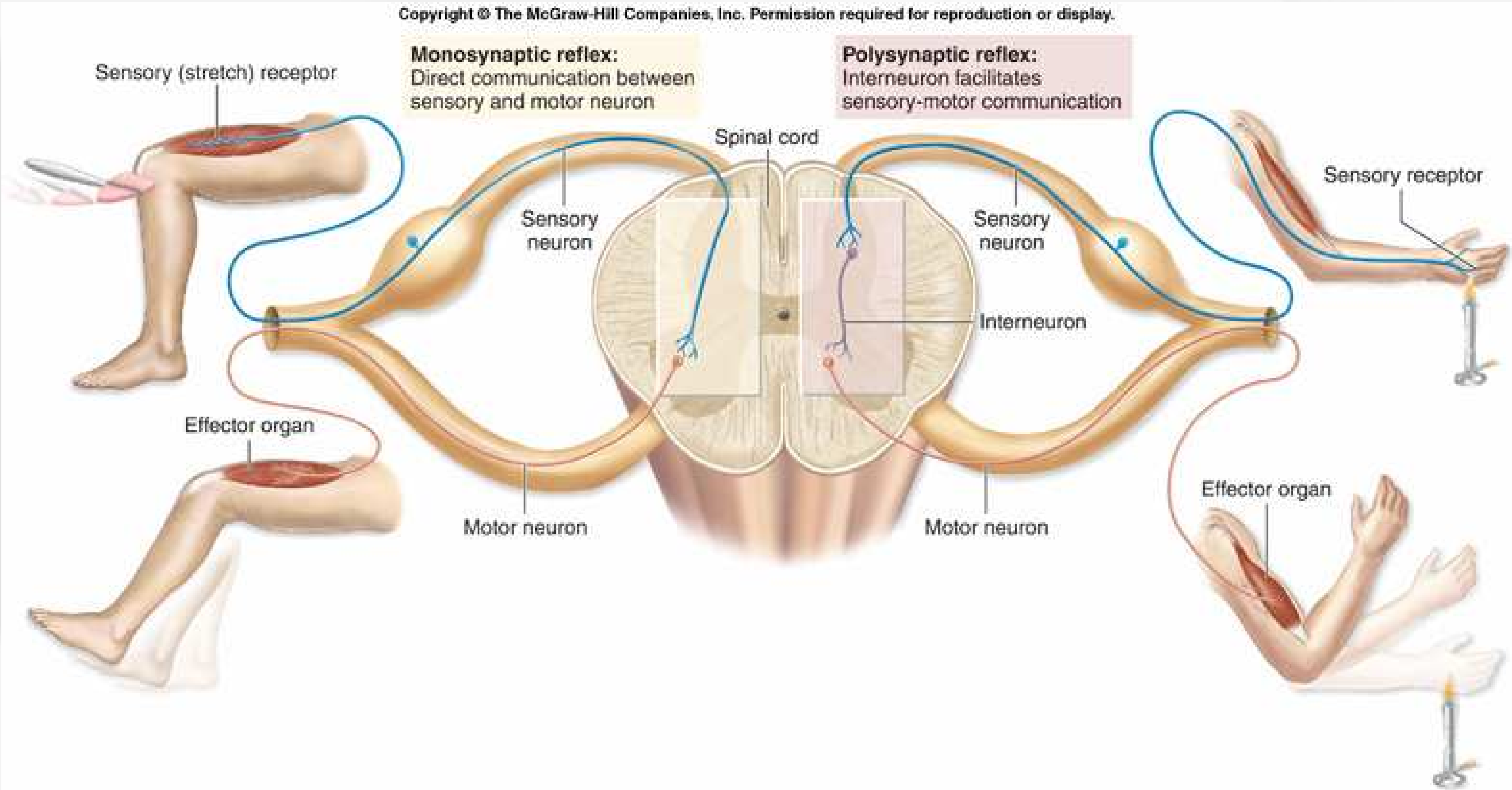
Sensation vs. Perception of pain

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

- Content of emotional distraction - participants could keep their hands in cold water longer when pictures they were shown were positive



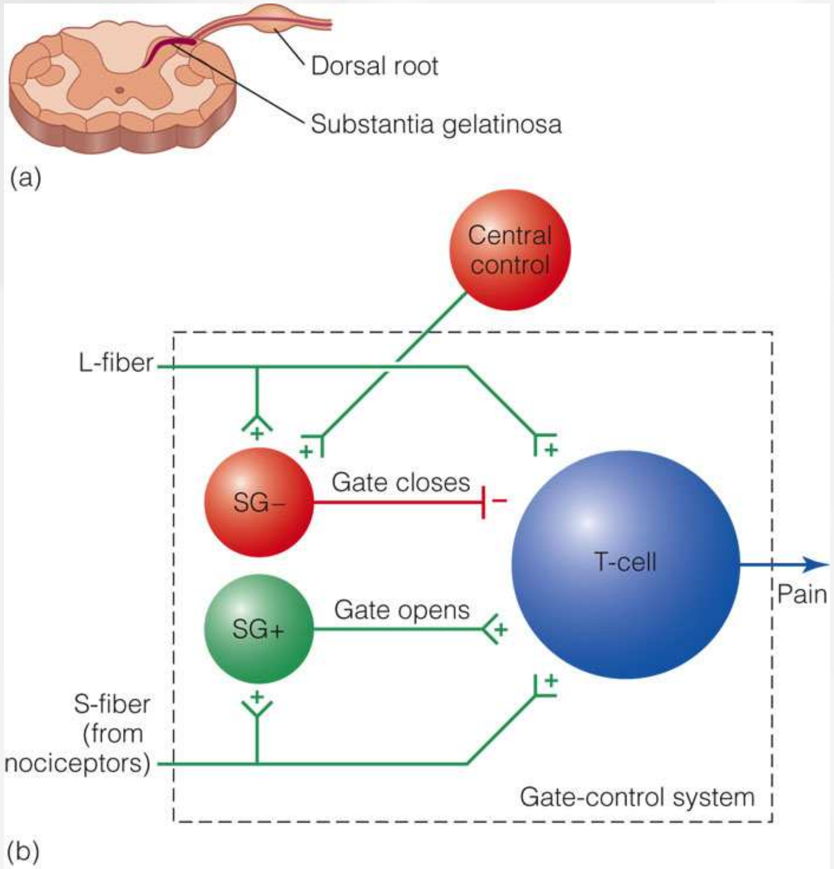
The Reflex Arc



Weird fact: Although this is a reflex (1) the body can be trained to override this reflex; and (2) an unconscious body (or even drunk or drugged bodies) will not exhibit the reflex.

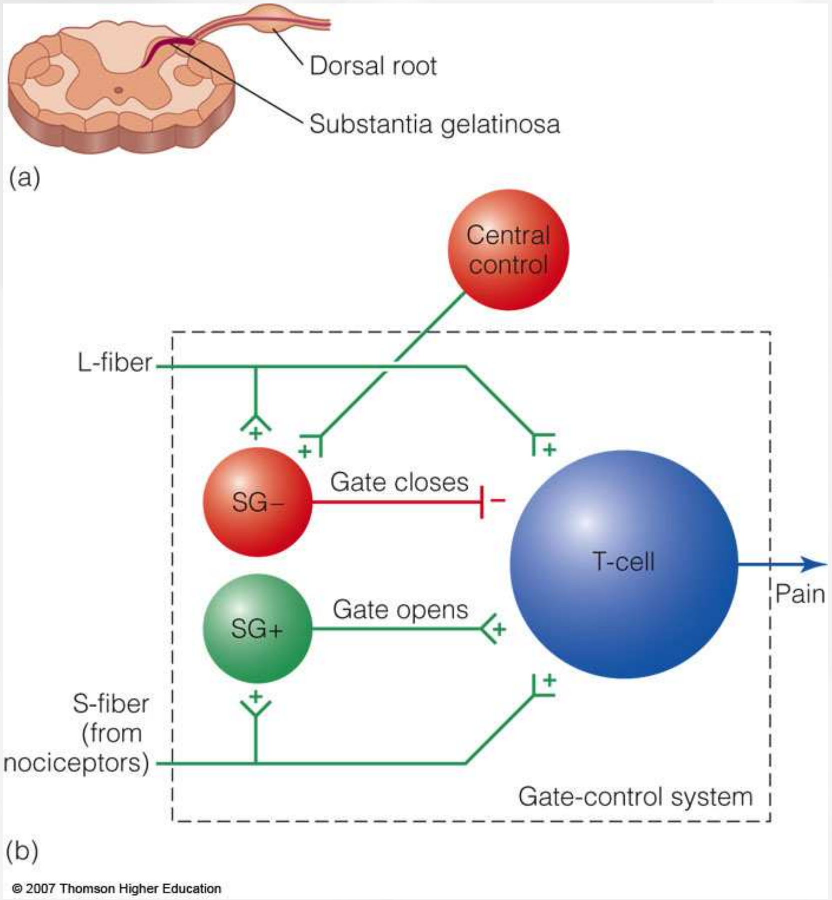
Gate Control Model of Pain Perception

- The “gate” consists of substantia gelatinosa cells in the spinal cord (SG- and SG+)
- Input into the gate comes from:
  - Large diameter (L) fibers - information from tactile stimuli
  - Small diameter (S) fibers - information from nociceptors
  - Central control - information from cognitive factors from the cortex



Gate Control Model of Pain Perception

- Pain does not occur when the gate is closed by stimulation into the SG- from central control or L-fibers into the T-cell
- Pain does occur from stimulation from the S-fibers into the SG+ into the T-cell
- Actual mechanism is more complex than this model suggests



Opioids and Pain

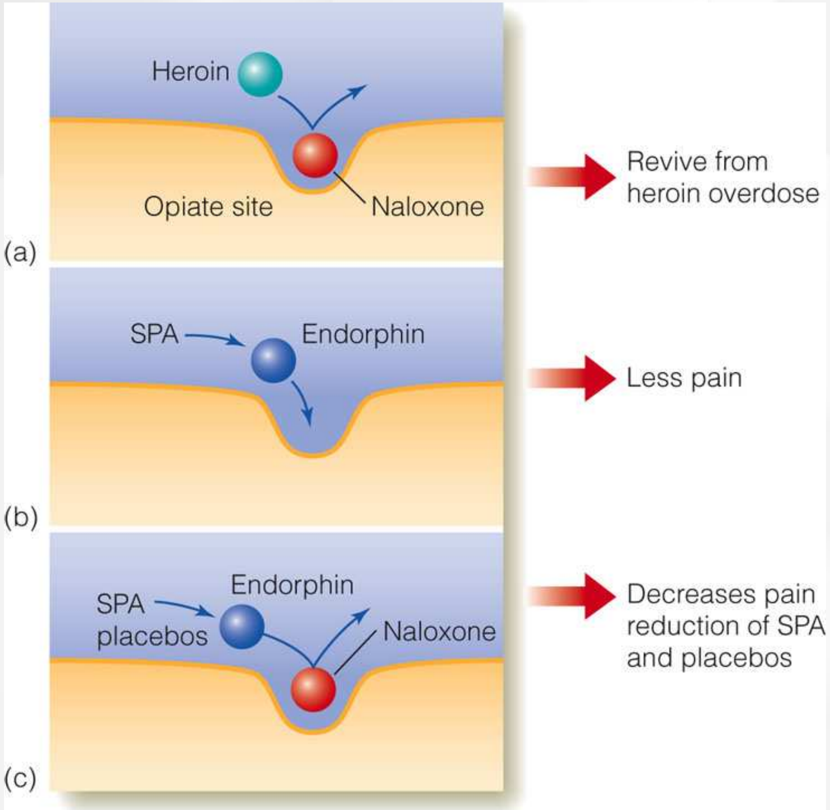
Stimulation of opiate receptor sites leads to a reduction of pain

Opiate receptors react to heroin, naloxone and endorphins.

Nalaxone can revive a victim of heroin overdose by blocking the receptor sites for heroin.

Placebos (stimulation-produced analgesia, or SPA) can lead to the release of endorphins

This could explain the ‘placebo effect’.



Pain Perception

"Give Me Novacaine"

Take away the sensation inside
Bitter sweet migraine in my head
Its like a throbbing tooth ache of the mind
I can't take this feeling anymore

Drain the pressure from the swelling,
This sensations overwhelming,
Give me a long kiss goodnight
and everything will be alright
Tell me that I won't feel a thing

So give me Novacaine

Men in a war
If they've lost a limb
Still feel that limb
As they did before

He lay on a cot
He was drenched in a sweat
He was mute and staring
But feeling the thing
He had not

I know how it is
When something is gone
A piece of your eyesight
Or maybe your vision

A corner of sense
Goes blank on the screen
A piece of the scan
Gets filled in by hand

-Susanne Vega

Pain in Social Situations

- 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 and participants reported feeling ignored and distressed