Introduction to Cognitive Neuroscience

Lecture 11: From Nerve Cells to Cognition The Internal Representations of External world

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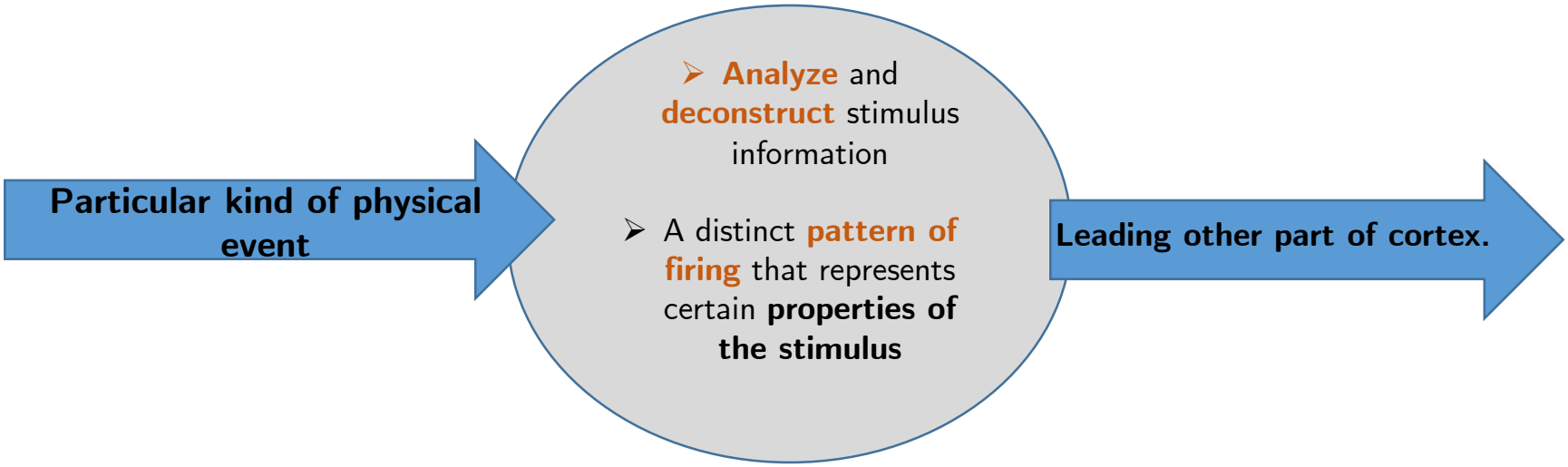
What we learned by examining single cell activity

- **Cellular studies** of the sensory systems provide important insight into how stimuli are **translated** by the brain into **sensations** and **planned action**
- **Coherent perception** according to the **brain's own rules**, rules that are **embodied** in the circuitry of the sensory system
- **Different modalities** of perception are processed **similarly** in different sensory system.

Sensor system



- The brain produces an **integrated perception** because nerve cells are **wired together** in precise and orderly ways according to a general plan that **does not vary greatly among normal individuals**
- Not exactly same, connections between cells can be **altered** by **activity and by learning**.
- We **remember specific events** **because** the structure and function of the connections between nerve cells are **modified by those events**

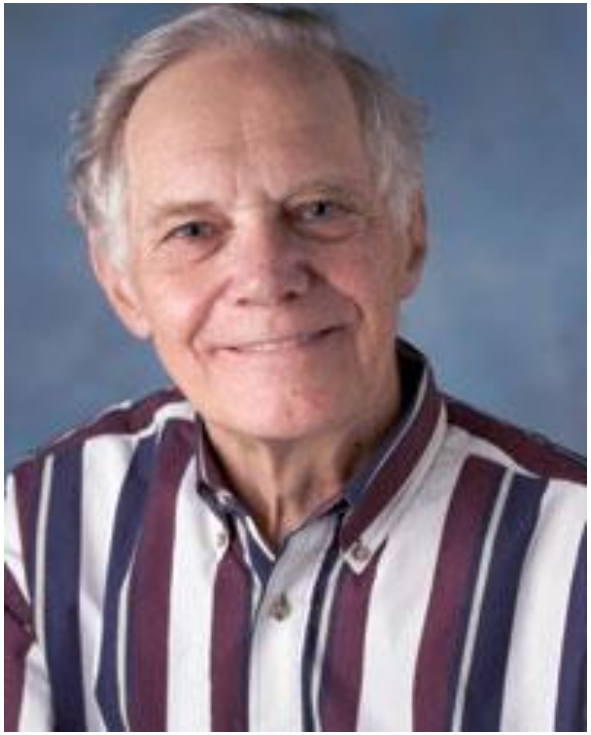
Cognitive neural science

- A **cellular approach** alone is **not sufficient** for understanding how the simultaneous activity of discrete sets of neurons **produces cognition**.
- For this task the brain **must be studied** as an **information processing organ**
- Combination of methods from a variety of fields to **solve brain problem**
  - cell biology,
  - systems neural science,
  - brain imaging,
  - cognitive psychology,
  - behavioral neurology,
  - computational neuroscience

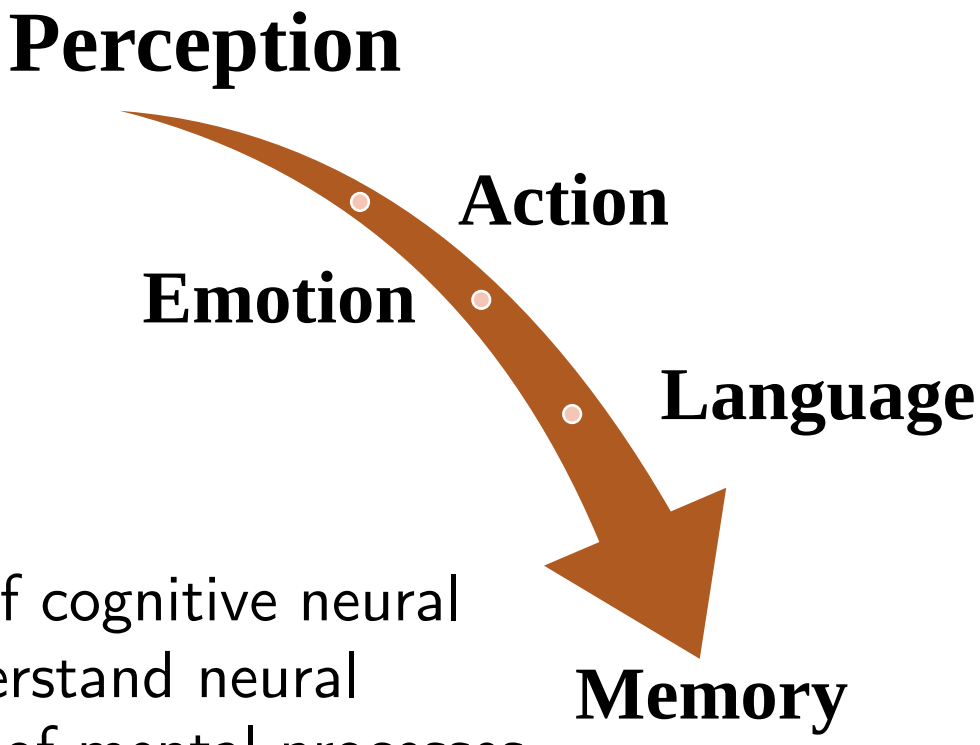
Ulric Gustav Neisser (December 8, 1928 – February 17, 2012) the "father of cognitive psychology"

It has been said that beauty is in the eye of the beholder. As a hypothesis . . . it points clearly enough to the central problem of cognition—the world of experience is produced by the man who experiences it . . . . There certainly is a real world of trees and people and cars and even books, and it has a great deal to do with our experience of these objects. However, we have no direct immediate access to the world, nor to any of its properties. . . .

Whatever we know about reality has been mediated not only by the organs of sense but by complex systems which interpret and reinterpret sensory information. . . . The term "cognition" refers to all the processes by which the sensory input is transformed, reduced, elaborated, stored, recovered and used. . . .



Five major subjects of cognitive neural science



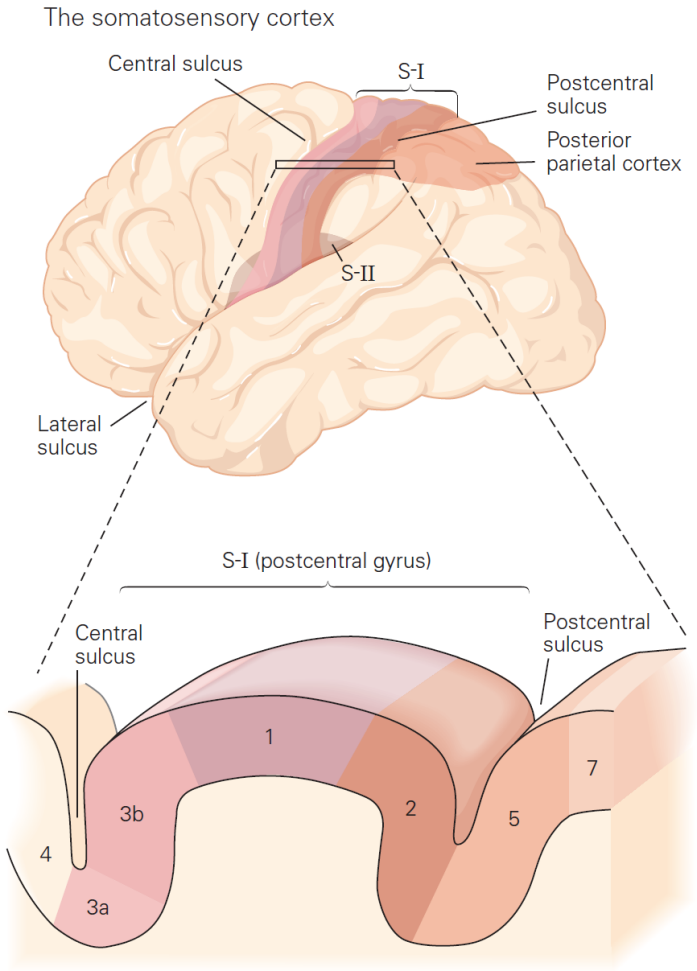
The major goal of cognitive neural science is to understand neural **representations** of mental processes

The brain has an orderly representation of personal space

- Neural **representation of the body surface** is a simple example of an **internal representation**
- **Touch** provides information about:
  - Shape, texture, and solidity of objects
- **Proprioception** provides information:
  - Static position and movement **limbs**.
- Tow **main features** of internal representation:
  - Pattern of activation in **population** (being on and off cells)
  - Pattern of firing rate in **individual** cells

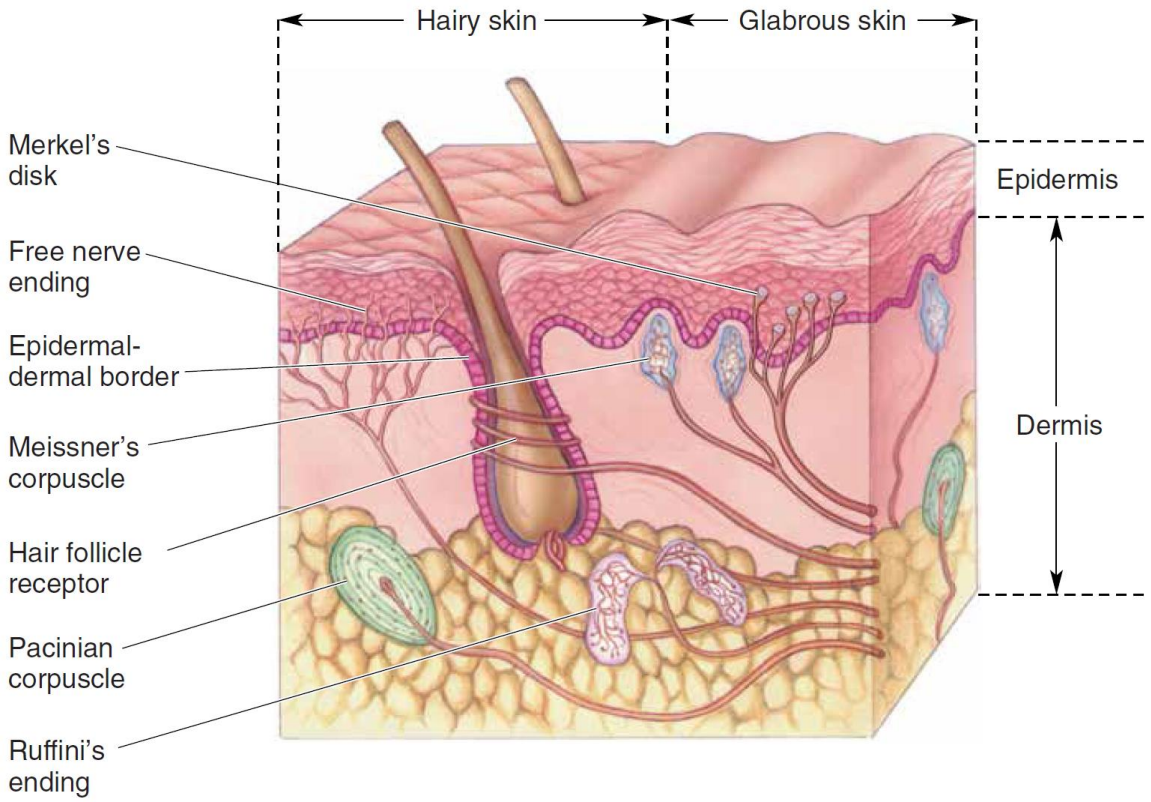
The somatosensory system in the cerebral cortex

- Each pathway contain some **synaptic relays**
  - In relay, the thousands of axons **terminate** on a cluster of **similar neurons**
- The **spatial relation** are **preserve** in different relays and brain.
  - That is, the **neighboring** receptors in the skin is conveyed to neighboring cells.

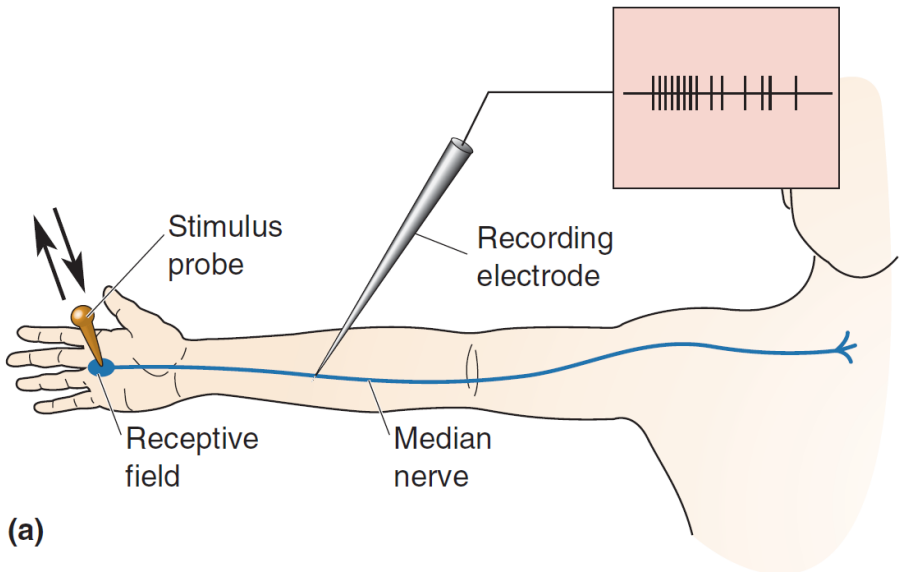


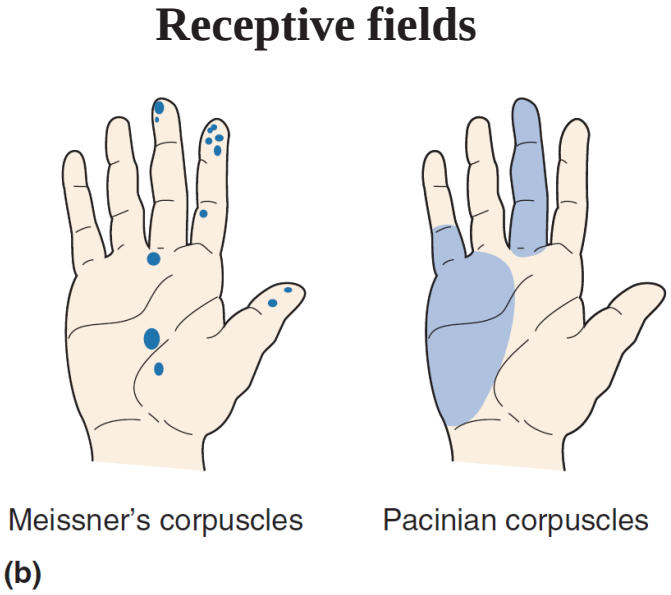
Somatic sensory receptors in the skin

- Receptors in skin: convert **mechanical** energy to neural signals



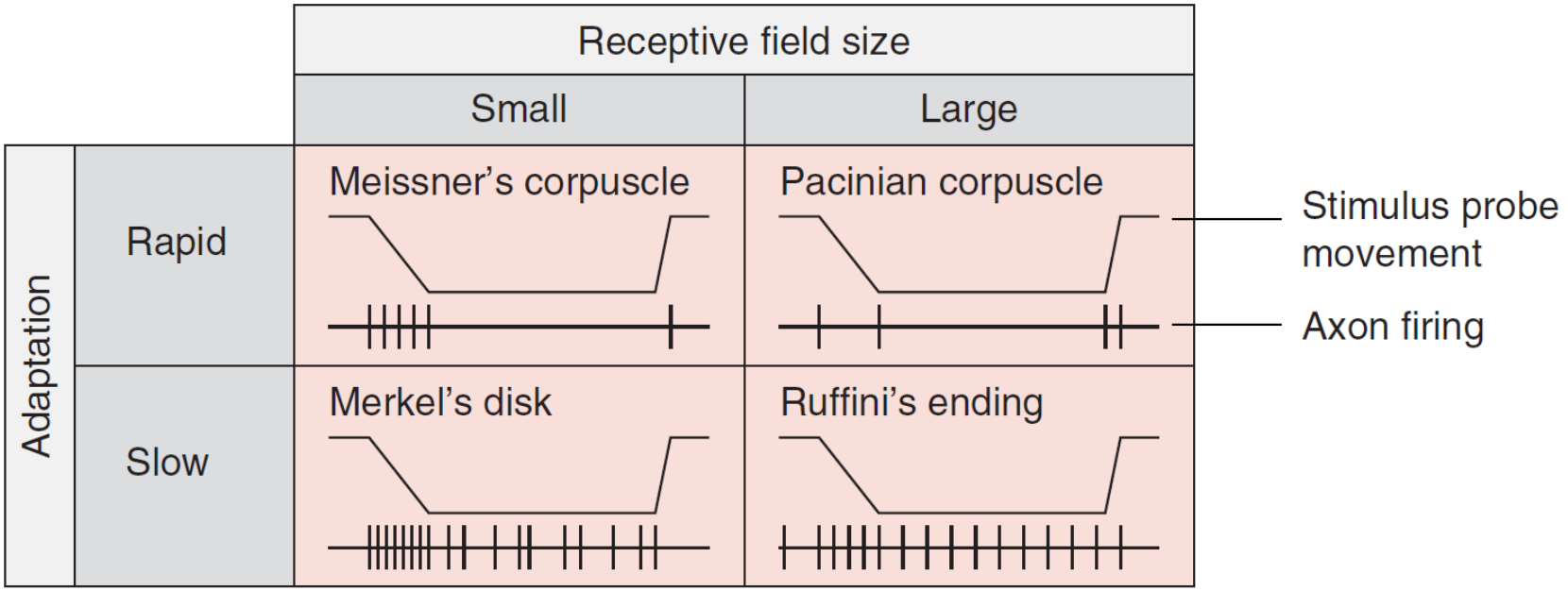
Testing the receptive fields of human sensory receptors



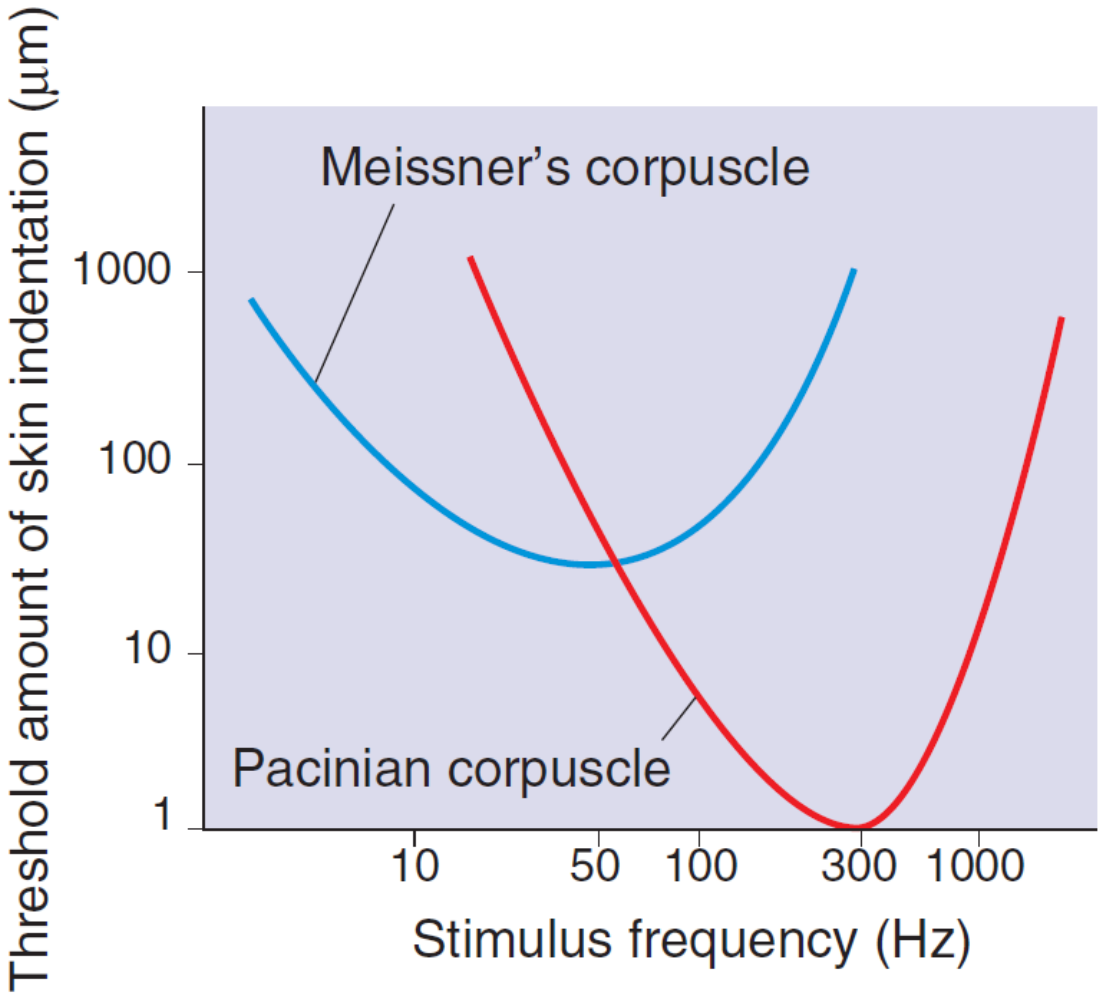


- By introducing a microelectrode into the **median nerve** of the arm

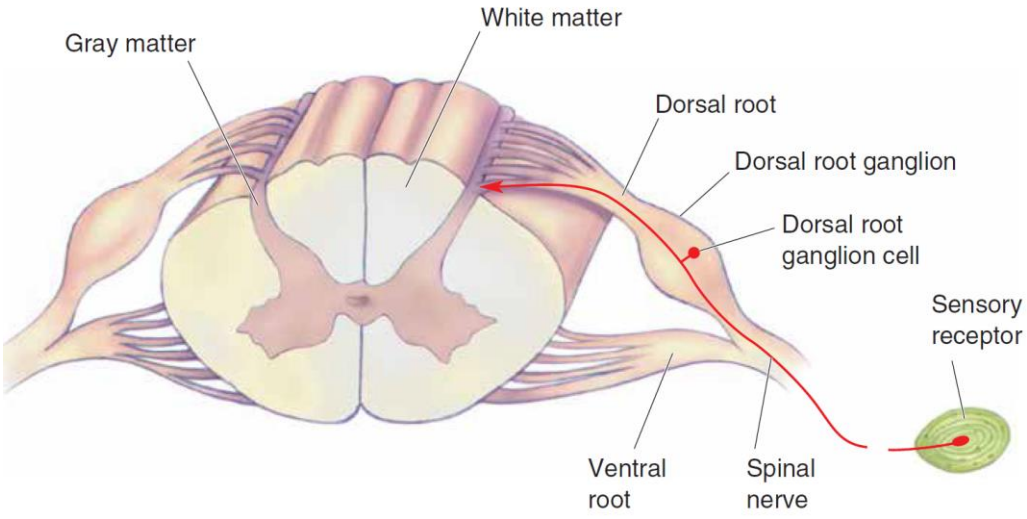
Variations of receptive field size and adaptation rate for four somatic sensory skin receptors.

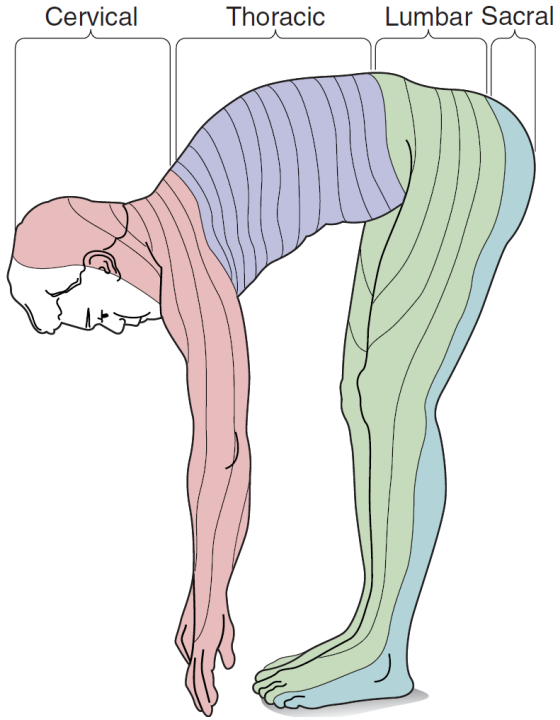


Frequency sensitivity of two rapidly adapting skin mechanoreceptors



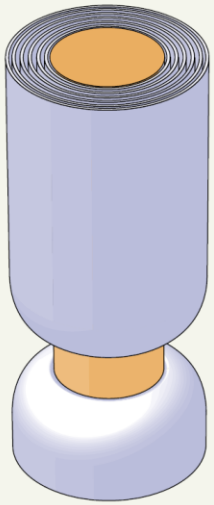
The structure of a segment of the spinal cord and its roots.

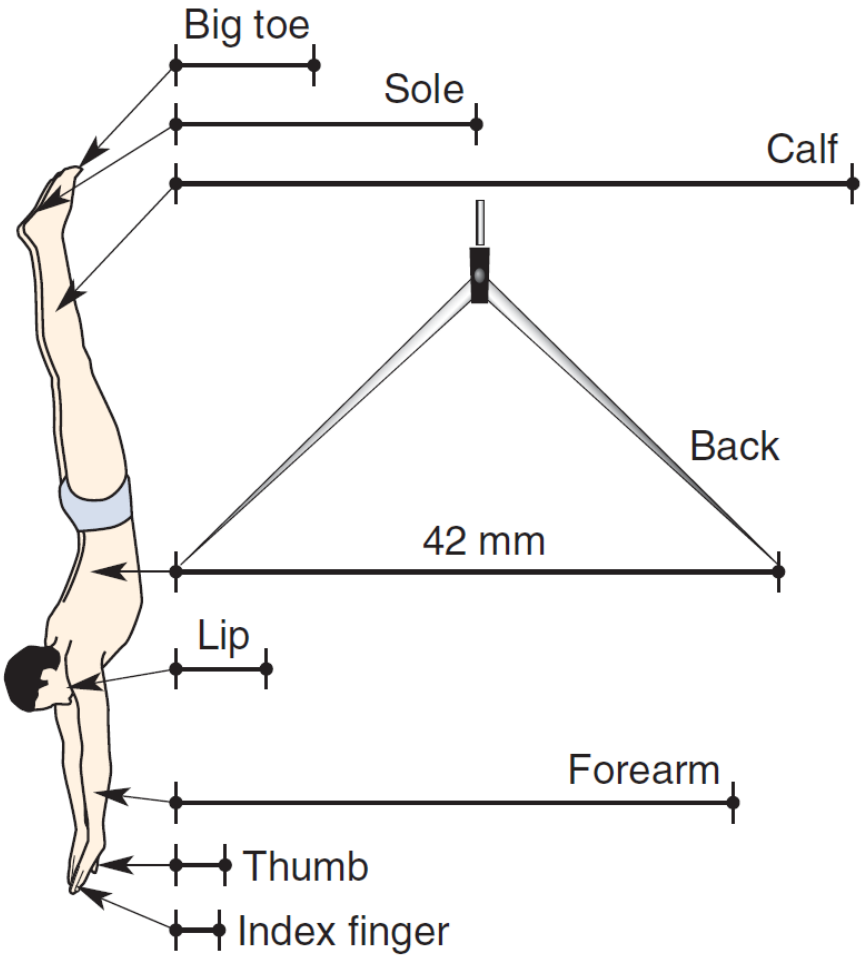




Sensory Organization of the Spinal Cord

Various sizes of primary afferent axons

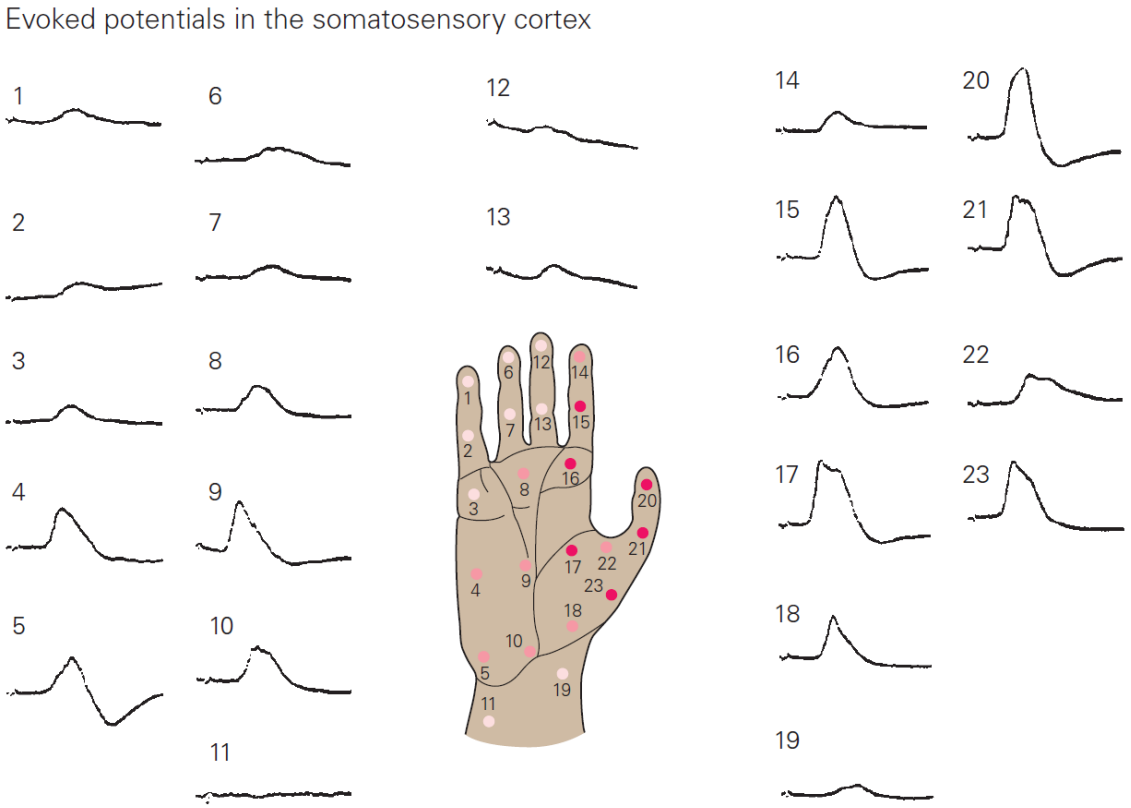
Axons from skin	Aα	Aβ	Aδ	C
Axons from muscles	Group I	II	III	IV
				
Diameter (μm)	13–20	6–12	1–5	0.2–1.5
Speed (m/sec)	80–120	35–75	5–30	0.5–2
Sensory receptors	Proprioceptors of skeletal muscle	Mechanoreceptors of skin	Pain, temperature	Temperature, pain, itch



Two-point discrimination on the body surface.

Wade Marshall in 1930; evoked potentials in the somatosensory cortex elicited by stimuli

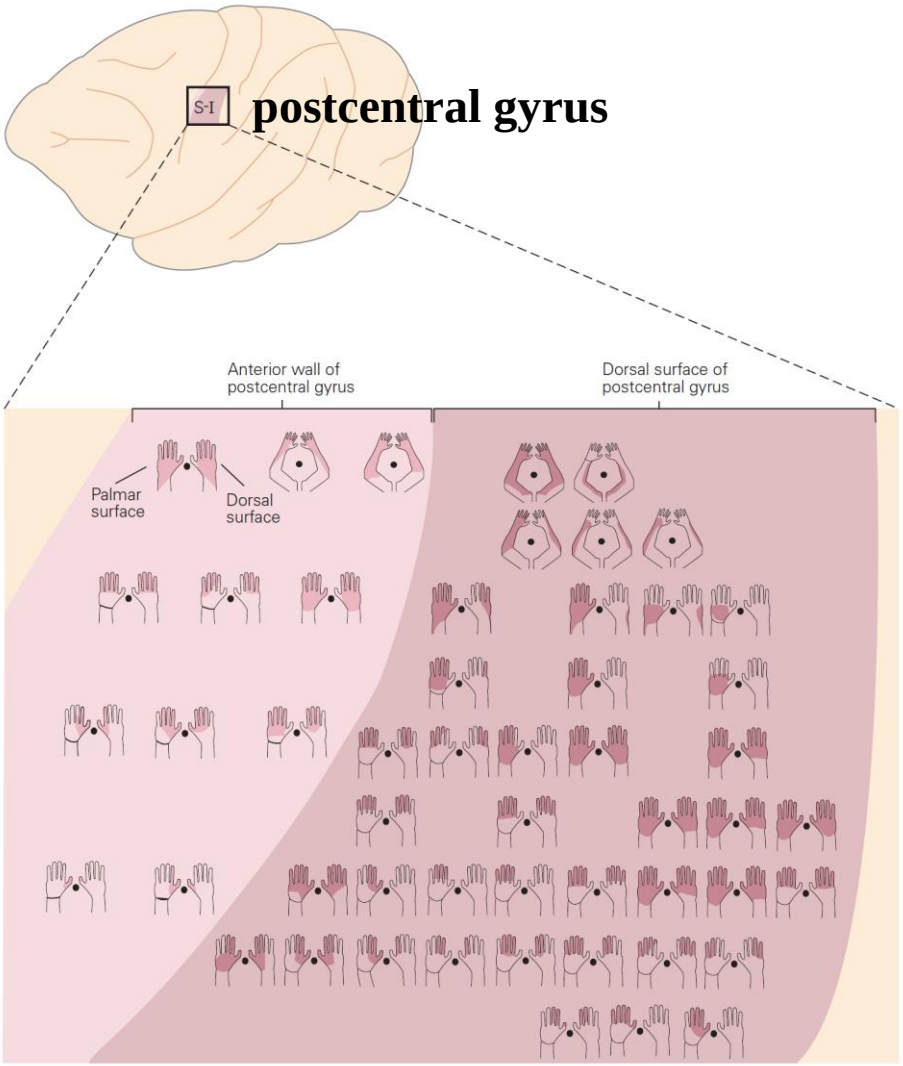
- The **evoked potentials** shown here are the **summed activity** of one large group of neurons in the **left postcentral gyrus** of a monkey, elicited by a light touch at different points on the **right palm**



An early map of the representation of the hands in the monkey cortex

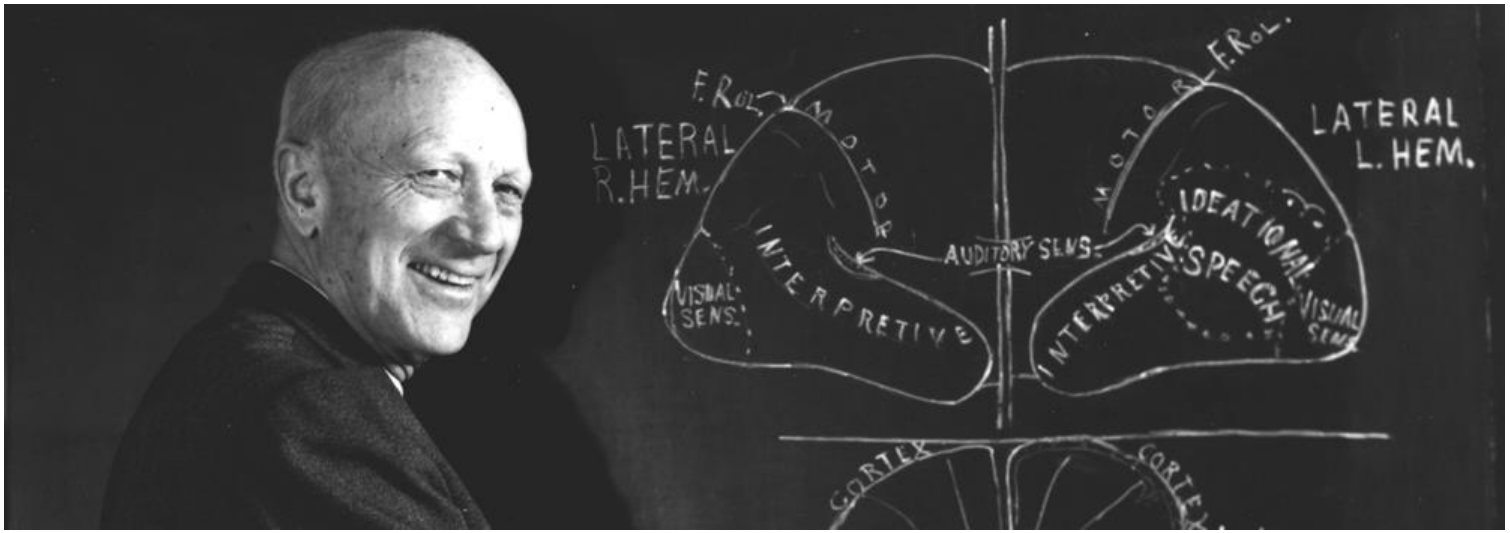
- **Recordings** were made in the primary somatic sensory cortex (S-I) in the postcentral gyrus.

- The area of the hand that **evoked a response** at each site is indicated by the **colored portion of the hand**

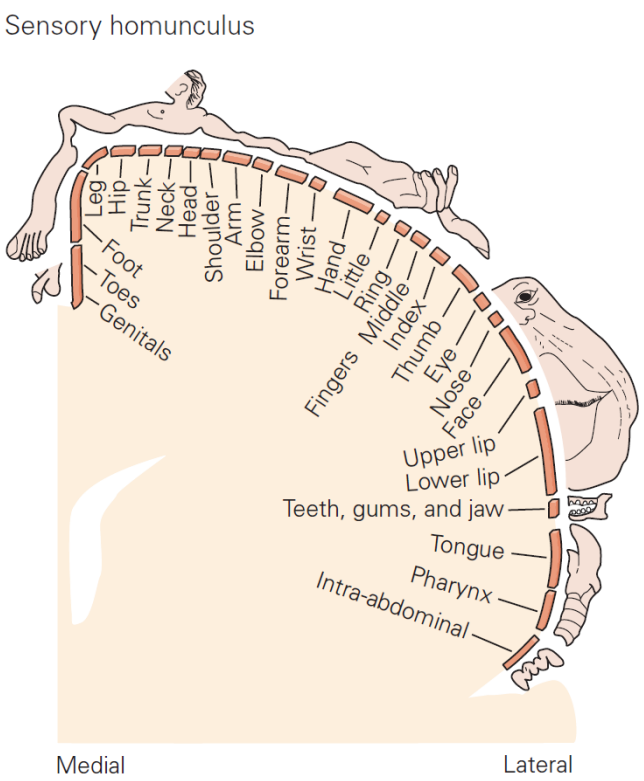


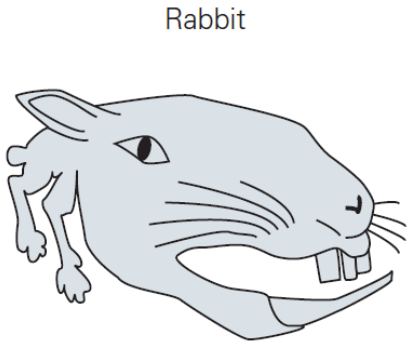
Map of human somatosensory cortex

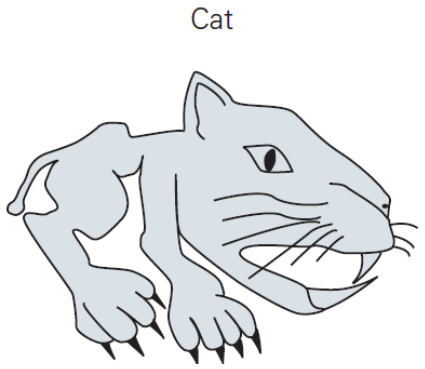
- It was mapped in the late 1940s by the Canadian neurosurgeon Wilder **Penfield** during operations for **epilepsy** and other brain disorders.
  - Working with locally anesthetized conscious patients
  - Stimulated various points on the surface of the postcentral gyrus

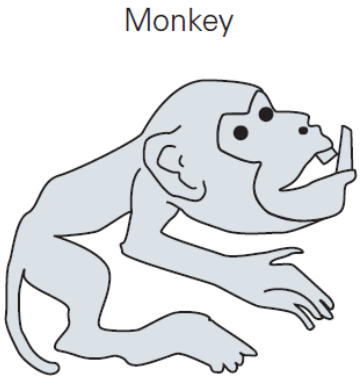


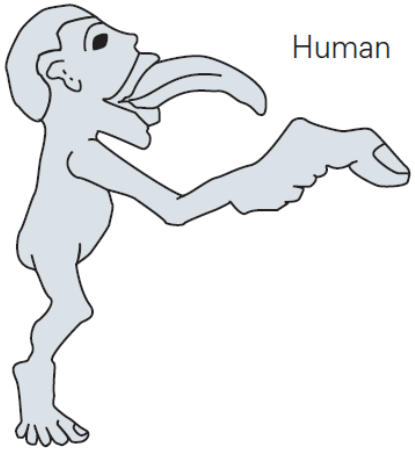
Cortical somatosensory maps in different species reflect different somatic sensibilities





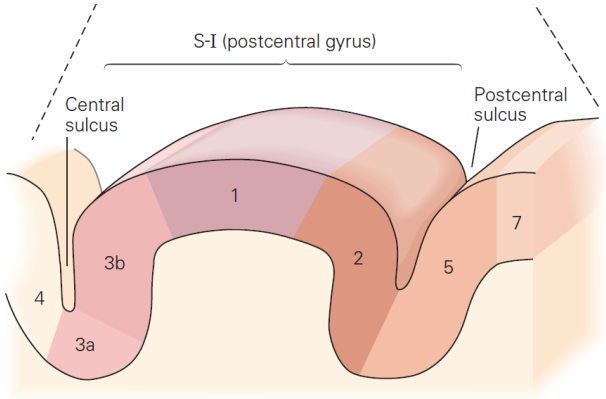






The cortex has a map of the sensory receptive surface for each sensory modality

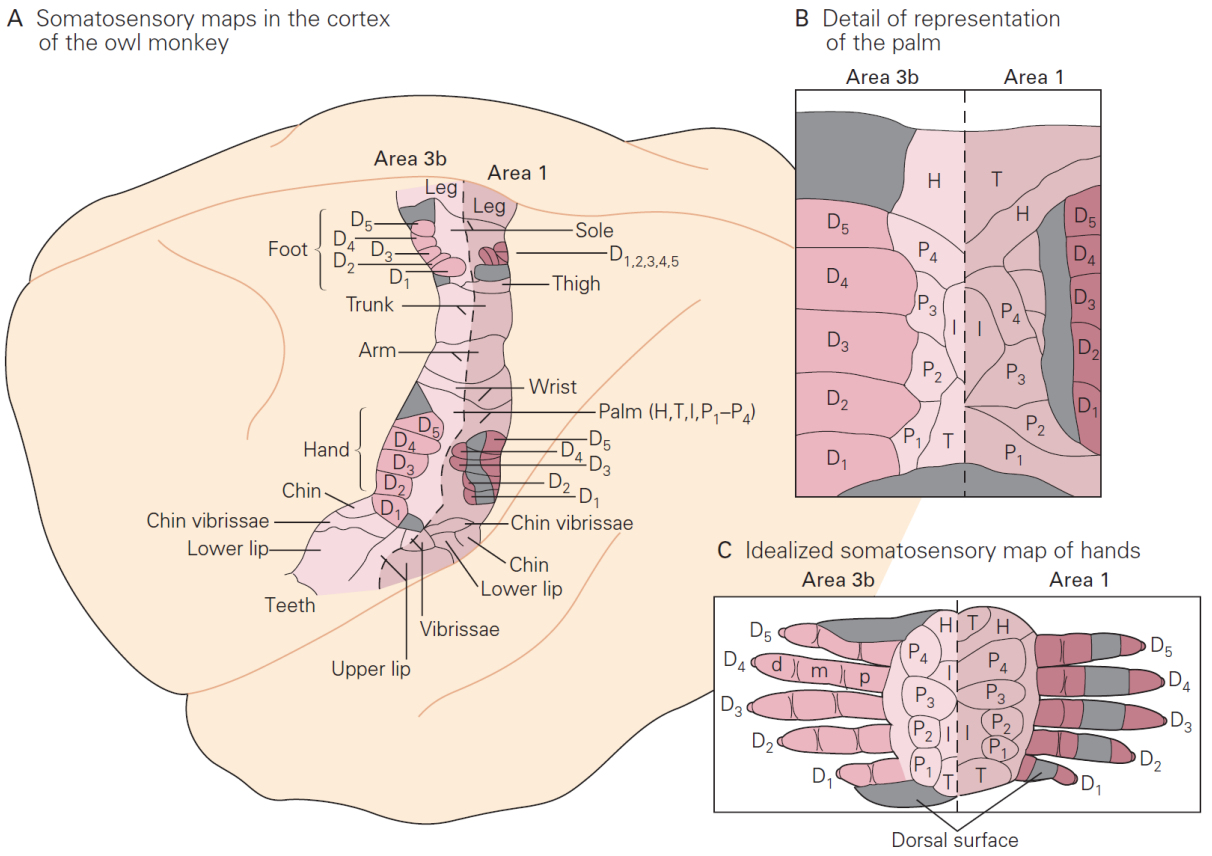
- Marshall showed that **retina and the cochlea**, are also represented **topographically** in the cortex
- Against Marshall theory (**one map**), there are **four complete map** in four area of somatosensory
- Each area processes a **distinct type of information**.
  - **3a**: receive information from **muscles and joints**, important for **limb** proprioception
  - **3b**: information from skin, important for **touch**
  - **Area 1:** for further analysis of 3b
  - Area 1 **combined** with muscles and joints information in **Area 2**.
- Lesion in **area 1** → **tactile discrimination**
- Lesion in **area 2** → **shape of grasp objects**



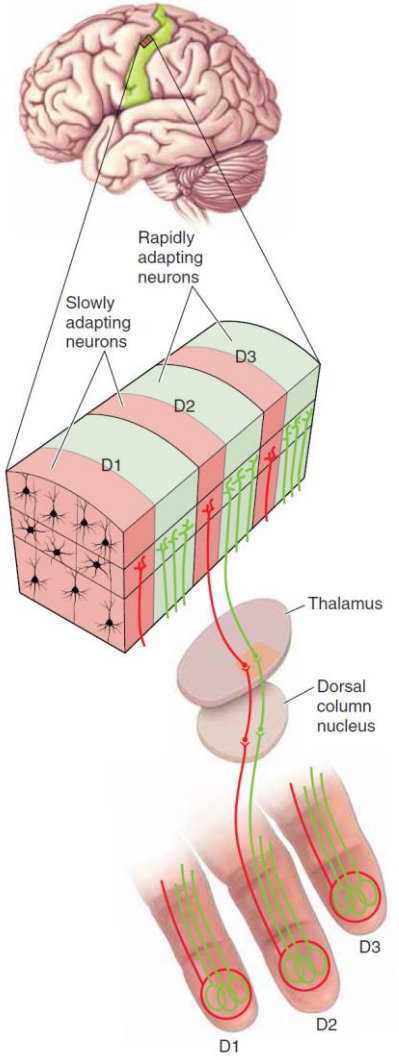
Each of the four areas of the primary somatic sensory cortex forms its own complete representation of the body surface

- Somatosensory maps of the body in Brodmann's areas 3b and 1

- The two maps are roughly **mirror images**.

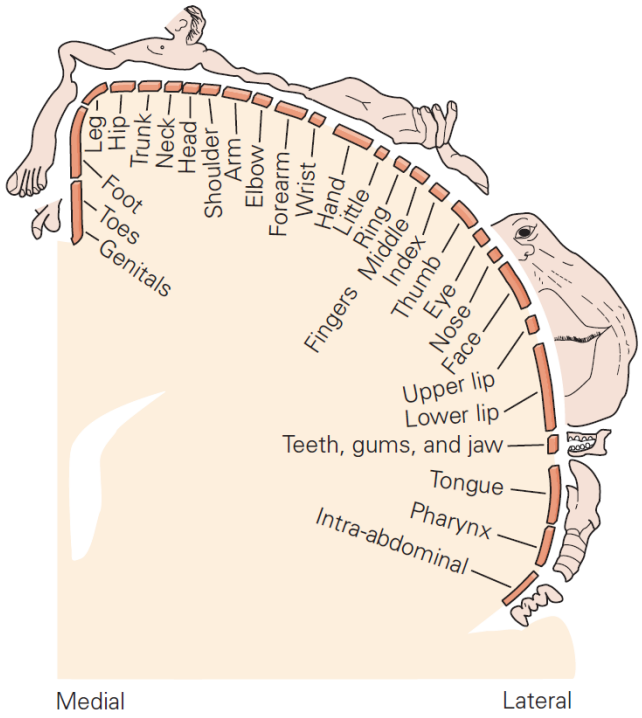


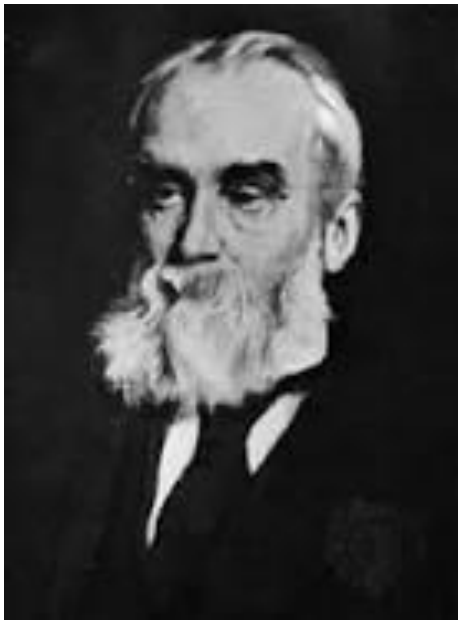
Columnar organization of S1's area 3b.



Jacksonian march seizure

Numbness and paresthesia might start at the fingertips, spread to the hand, up the arm, across the shoulder into the back, and down the leg on the same side.



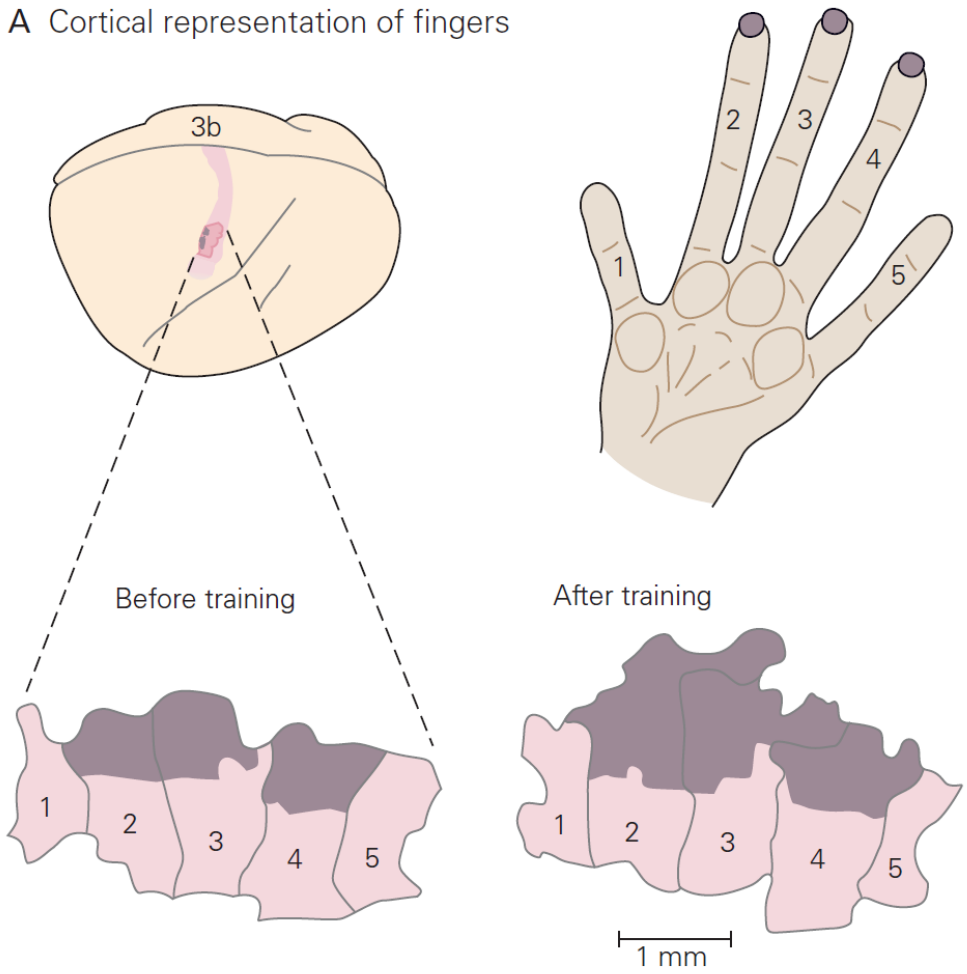


The internal representation of personal space can be modified by experience

- Sensory map is not **hard-wired** (a path from sensory to cortex)
- Cortical map change a lot, even in **adults**
- Experiment to test it:
  - Monkey **touch by middle** finger → after months the **related cortex** greatly **expanded** and other areas which had not been used was reduced
  - **Severing** the hand **sensory** nerve for 10 years → **change the map**
- Dramatic change in **afferent connections** occurs because of experience, disease, lesion

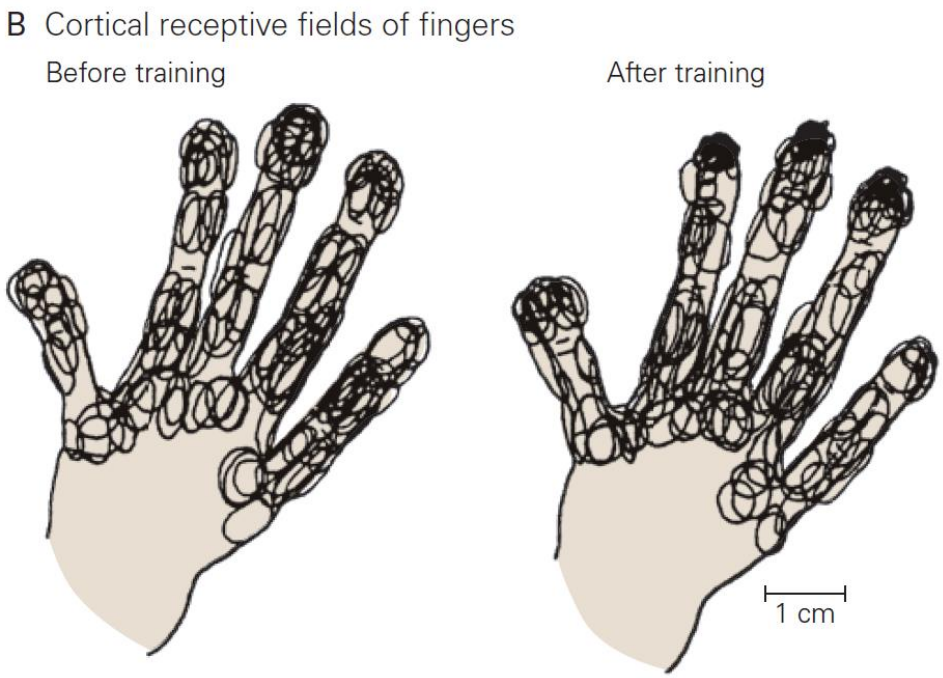
Increased use of a finger enlarges the cortical representation of that finger.

During training the monkey performed a task that **required** use of the **tips of the distal phalanges of digits 2, 3**, and occasionally 4 for 1 hour per day



Training increased the number of receptive fields in the distal tips of the phalanges of digits 2, 3, and 4.

The **receptive field for a cortical neuron** is the area on the skin where a tactile stimulation either excites or inhibits a cell.



How do these changes occur?

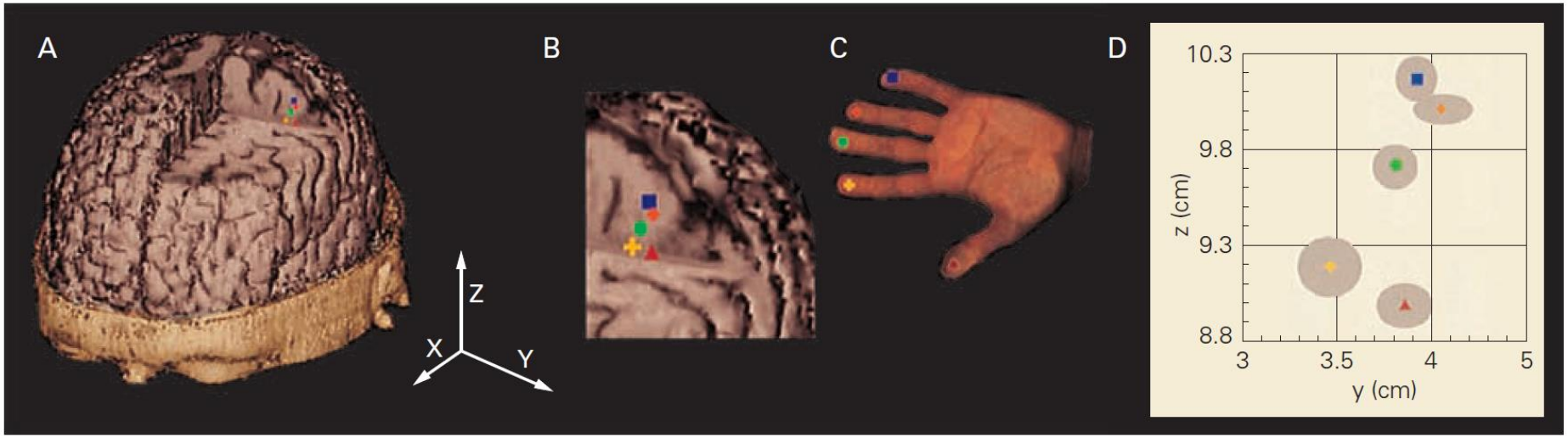
- Afferent connection **fine-tuned during development**
  - When the firing of **pre** and **post**synaptic cells is **correlated**
  - Cells that fire **together** → **strengthen their connection** together
- **Michael Merzenich experiment**
  - Surgically **connecting** the skin of two adjacent fingers → both finger always **used together** →increase the **correlation of activity** from adjacent fingers →**abolishes the sharp distinction** in neural map

Syndactyly

- **Congenital fusion of fingers**(syndactyly)
- Maps of hand with a **precision** of millimeter
- Syndactylic hand has **shrunken representation**
  - When it is separated→ newly separated fingers became **individually represented within weeks**



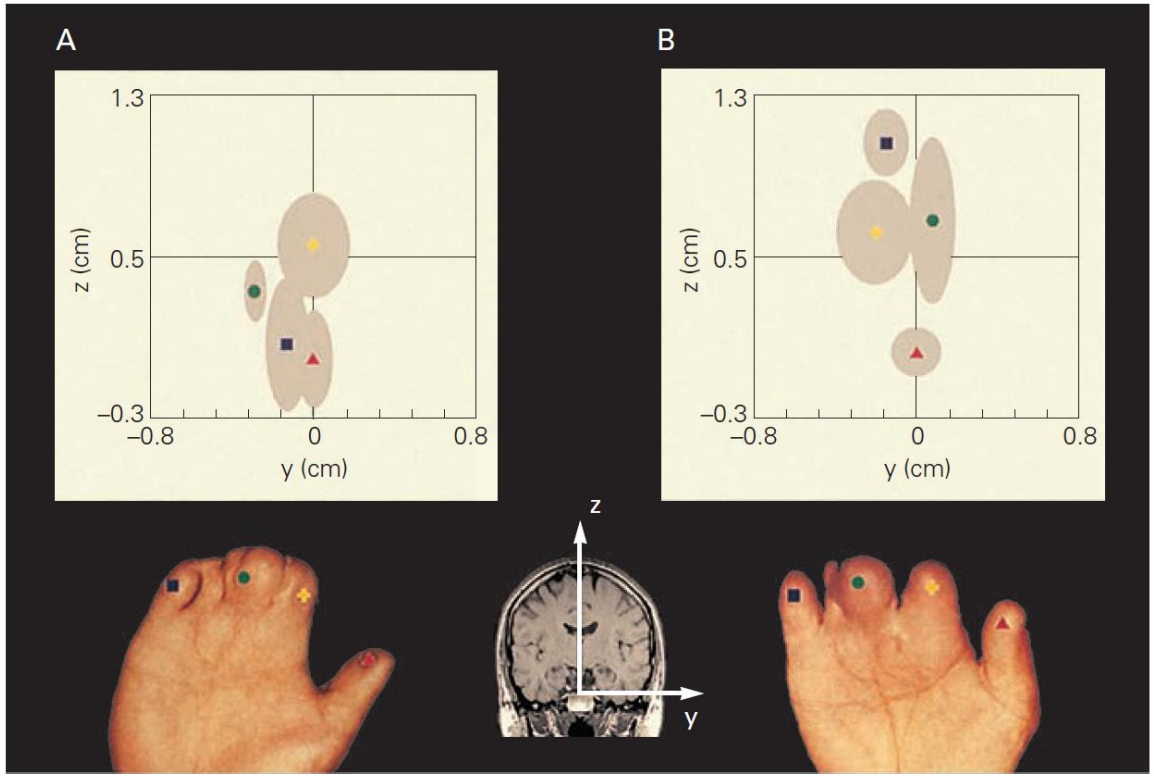
The representation of the hand in the somatosensory cortex can be visualized with magnetic encephalography(MEG)



Cortical representation of the hand changes following surgical correction of syndactyly of digits 2 to 5

Preoperative representation is **abnormal** and **lacks any somatotopic organization**

Twenty-six days after surgical separation

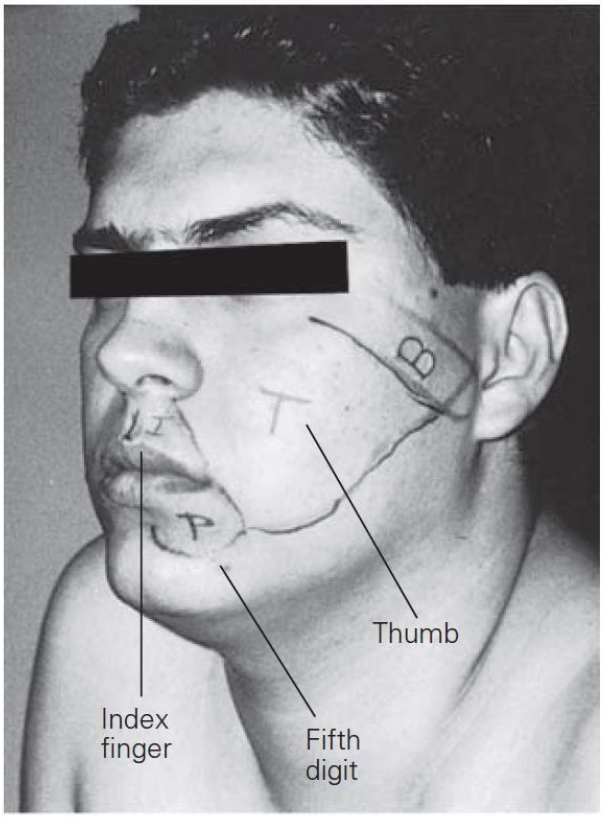


Phantom limb syndrome

- **Somebody with amputated limbs** continue to have **vivid** sensory **experience of missing limb**
  - Sense presence, feels move around, feels it try to **shake hands** when greeting some one
  - **Terrible pain** is often felt in the phantom limb
  - Removing scar or cutting its sensory, may relieve pain in case
- How are **changes in cortical maps** **interpreted** by the brain and how do **they shape perception**

Phantom limb sensations can be evoked by stimulating particular areas of skin.

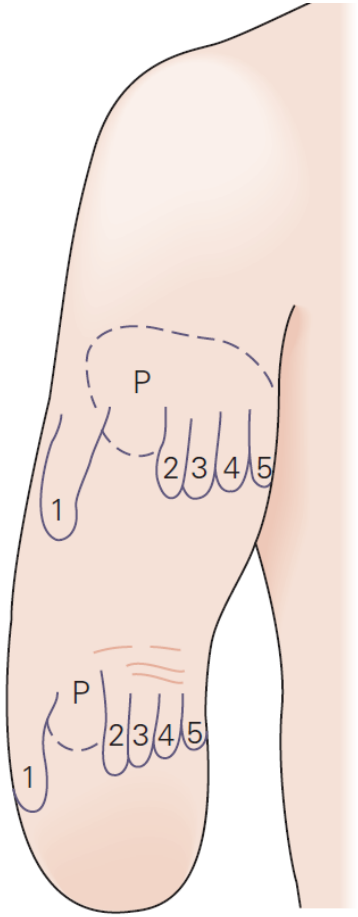
- Arm amputated experience
- Sensation of the missing hand when their faces and upper arms are touched
- **Regions of the body** that evoke referred sensations are called ***reference fields***
- Patient was tested 4 weeks after amputation.
- I, P, and B evoke sensation of the phantom index finger, pinkie, and ball of the thumb,



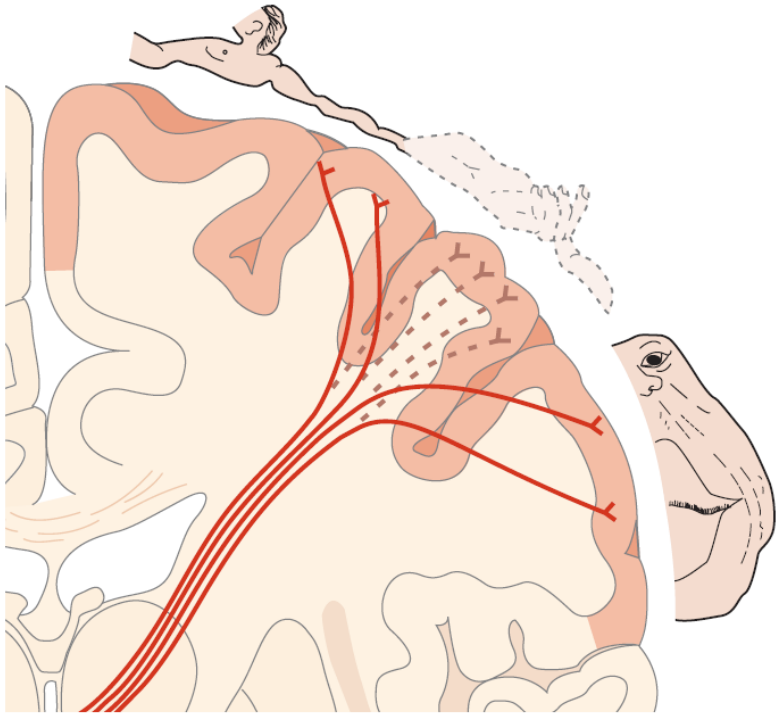
Cause of phantom limb

- Imaging studies:
- Caused by a **rearrangement of cortical** circuits
- As the afferent from the lost hand **wither** → **adjacent** afferent fibers **expand** into their place (just as the mentioned monkey)
- **Remapping of referred sensations**:
  - The area that before represent hand, now **receive afferent from at least one other site**
- Stimuli in face and upper arm (and other near place in homunculus) →elicit referred sensation of phantom limb
- Change in the **arrangement of sensory afferent** → change in **readout of sensory map**

When the patient imagined **pronating** his phantom lower arm, the entire upper map shifted in the same direction by approximately 1.5 cm.

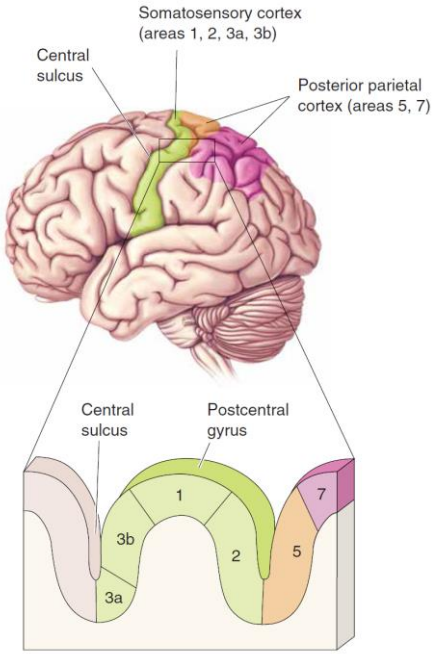


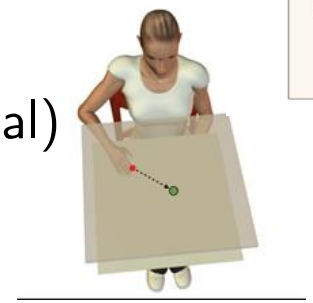
Hand area is **flanked** by the face and the arm.
Rearrangement of these cortical inputs → some types of phantom limb sensation.



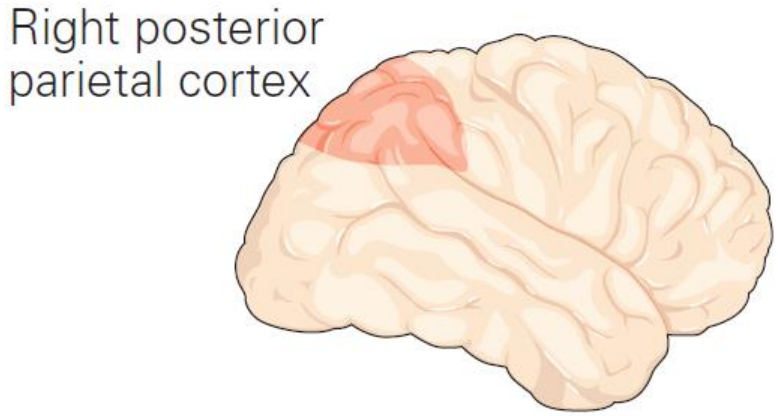
Extrapersonal space is represented in the posterior parietal association cortex

- 3a, 3b, and 1 project to area 2 (**unimodal**) and posterior parietal (5 and 7); **multimodal** association area.
- **PP** also receive input from **visual** and **auditory** system and **hippocampus** → **integrate** different modality to make **spatial percepts** of **extrapersonal** space
- Lesion to PP defects:
  - Spatial perception (personal or peripersonal)
  - Visuomotor
  - Selective attention





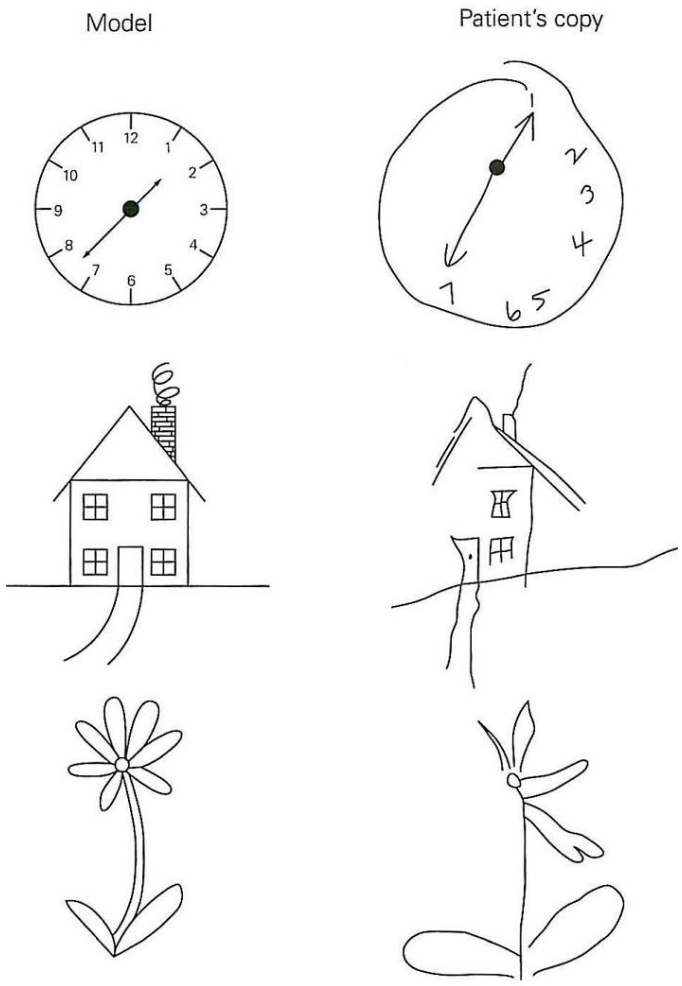
- **Damage** to PP produce object agnosia
  - Inability to **process** sensory information
  - Inability to **recognize** certain kind of objects
  - **Astereognosis** ***:*** unable to recognize **through touch**



Personal neglect syndrome

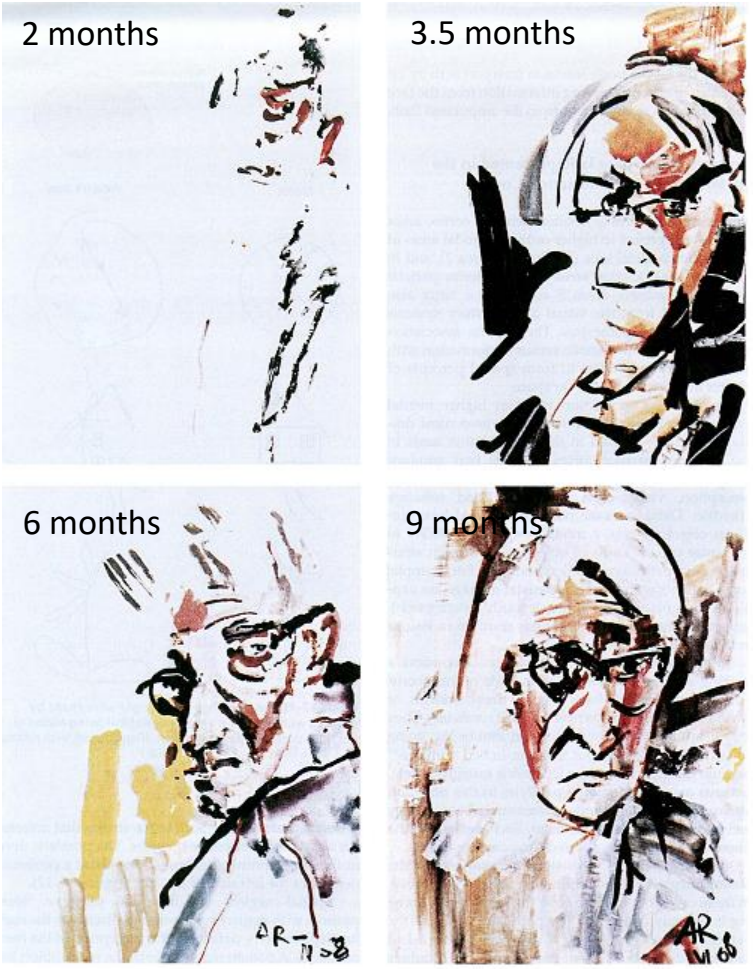
- Striking deficit in **awareness** of one **side of their body**
- Deny or disown their left arm or leg
  - Who put this arm in bed with me?
- The **idea of having a left limb** is foreign to them
- Deny the **paralysis in this limb** and attempt to leave the hospital prematurely because they feel **nothing is wrong with them (***Anosognosia:* Denial about a disability
- **High lesion → neglect extend from near space to far space**

Unilateral visual neglect following lesion of the right posterior parietal cortex



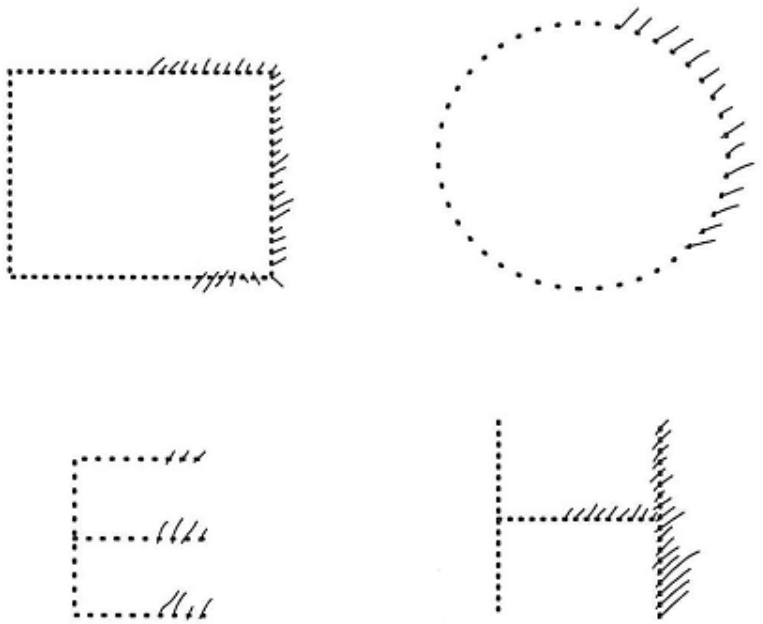
Spatial neglect

German artist who suffered a stroke that affected his **right posterior parietal** cortex.



Spatial neglect can be quite selective

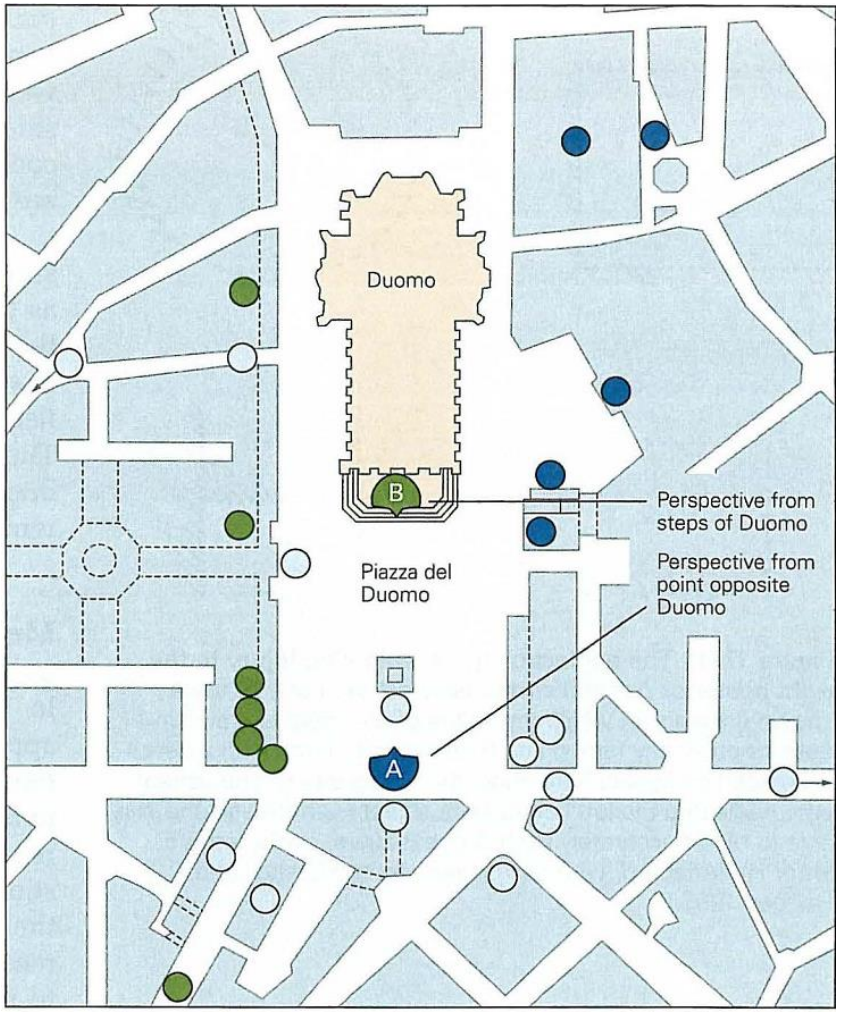
- Injury to the **right posterior parietal** cortex
- Asked to **mark** with a pencil **each dot**
- She was able to **report** accurately each shape

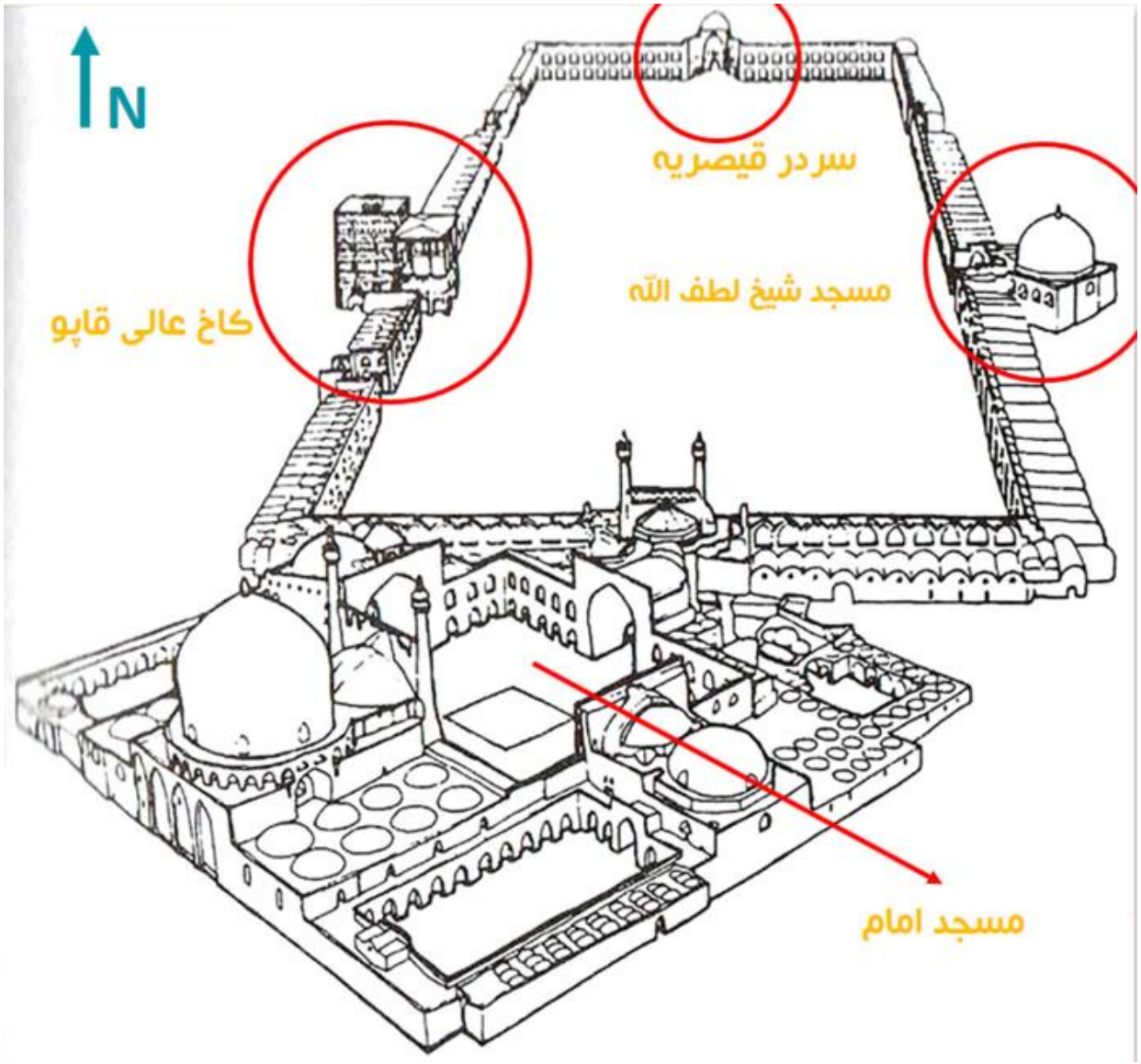


Representational neglect Milanese patients

- Neglect of one half of a **remembered image**
- Asked them to **describe from memory** the building around square
- They were able to identify all the buildings on the **right side of the square** (ipsilateral to the lesion)
- Asked imagine to be in the other side → report other side of plaza
- **Memory of external space** is perceived in relation to the **vantage point of the observer**, not simply of that of objects in the environment
- Memories for each half of the visual field are **accessed through the contralateral hemisphere**
  - **Representation and access to memory is different**
- Lesion to PP impairs **real time and stored visual information**

Recall only landmarks on their right in the Piazza del Duomo in Milan

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Pain

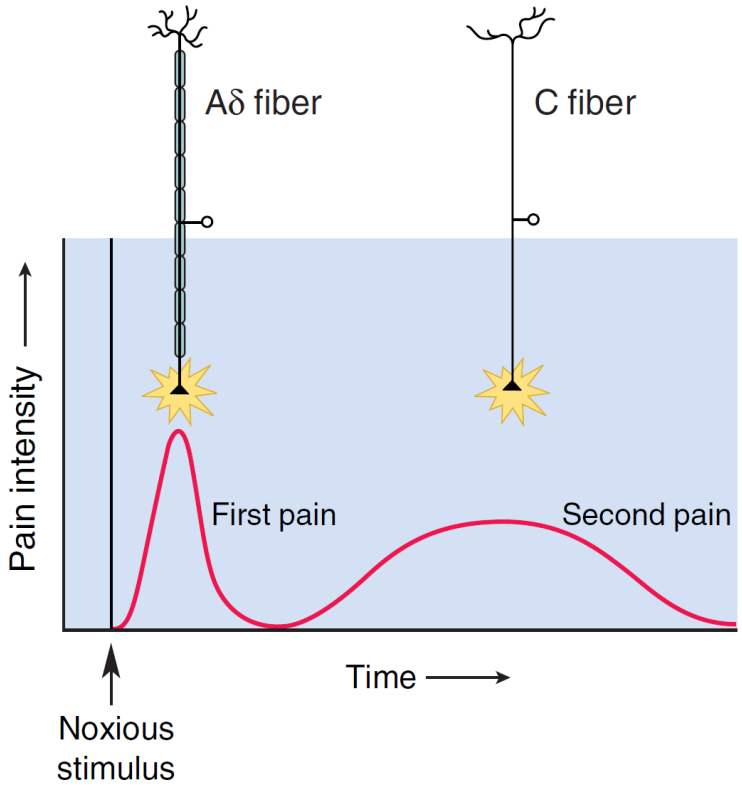
- In addition to the mechanosensitive touch receptors we have described so far, **somatic sensation** depends strongly on **nociceptors** , the free, branching, unmyelinated nerve endings that **signal that body tissue is being damaged** or is **at risk of being damaged**.
- *Pain* is the feeling, or the perception, of **irritating**, sore, **stinging**, **aching**, **throbbing**, miserable, or unbearable sensations arising from a part of the body.
- *Nociception* is the **sensory process** that provides signals that trigger pain.
- Pain may be **agonizing**, even **without activity in nociceptors**.
- Nociceptors are **activated by stimuli** that have the **potential** to cause **tissue damage.**
  - mechanical stimulation, extremes in temperature, oxygen deprivation, and exposure to certain chemicals.

Types of nociceptors

Receptor type	Fiber group[1]	Fiber name	Modality
Nociceptors			Pain
Mechanical	Aδ	III	Sharp, pricking pain
Thermal-mechanical (heat)	Aδ	III	Burning pain
Thermal-mechanical (cold)	C	IV	Freezing pain
Polymodal	C	IV	Slow, burning pain

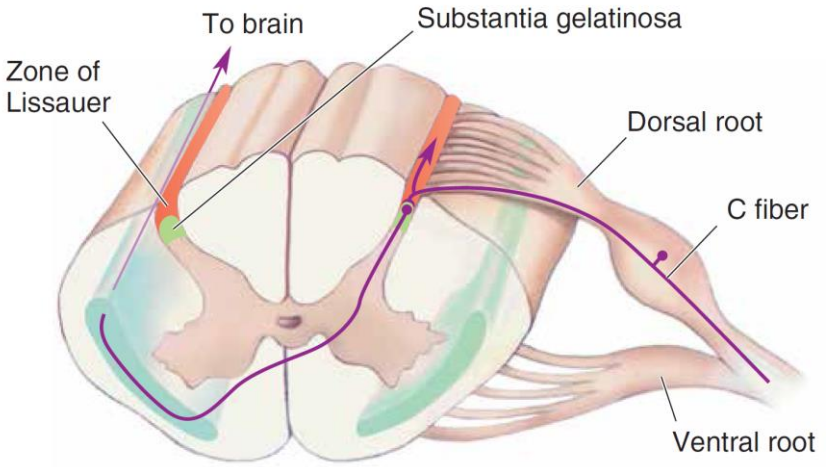
Hyperalgesia:

The unusual sensitivity of skin, joints, or muscles that have already been damaged or inflamed

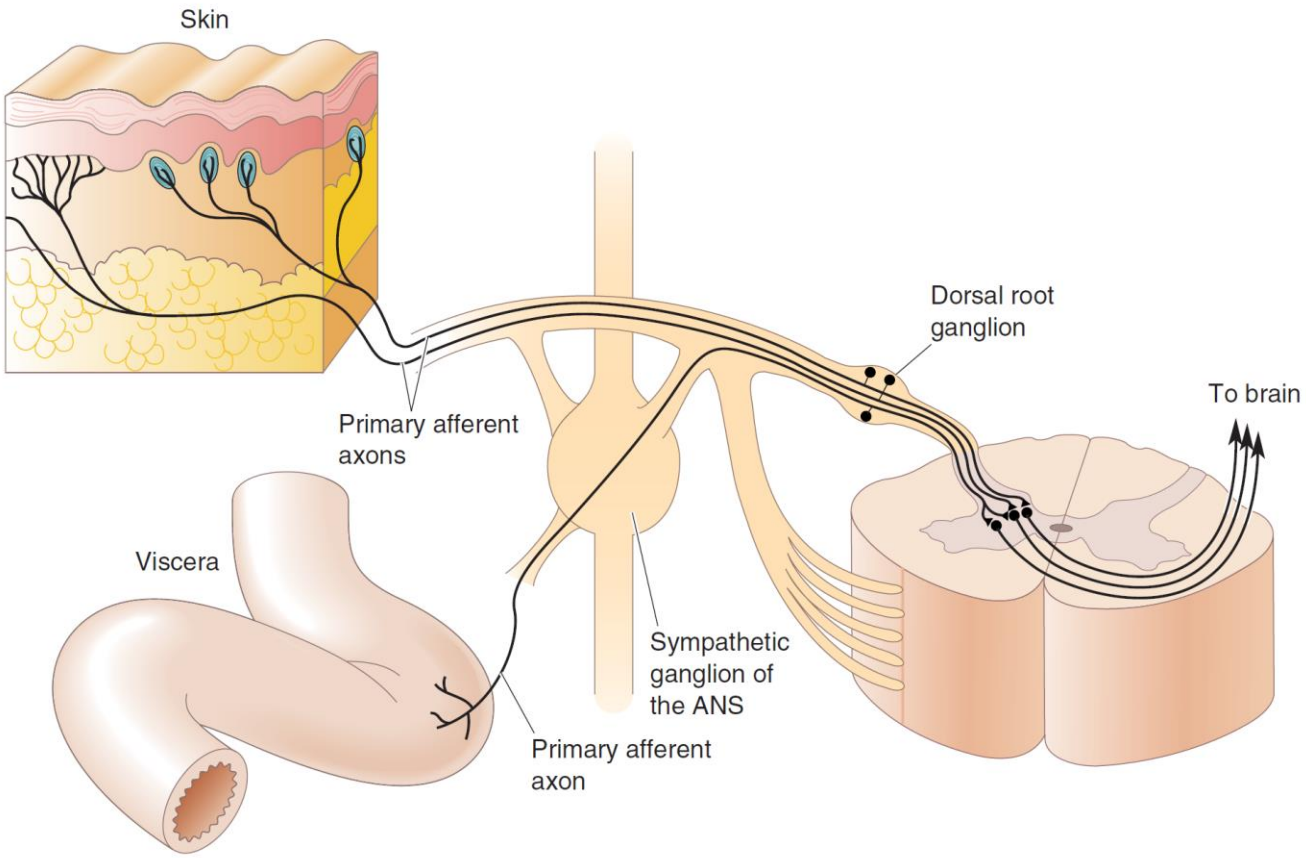


First and second pain. The first pain sensation registered by noxious stimulation is mediated by fast Aδ axons. The second, longer lasting pain sensation is mediated by slow C fibers.

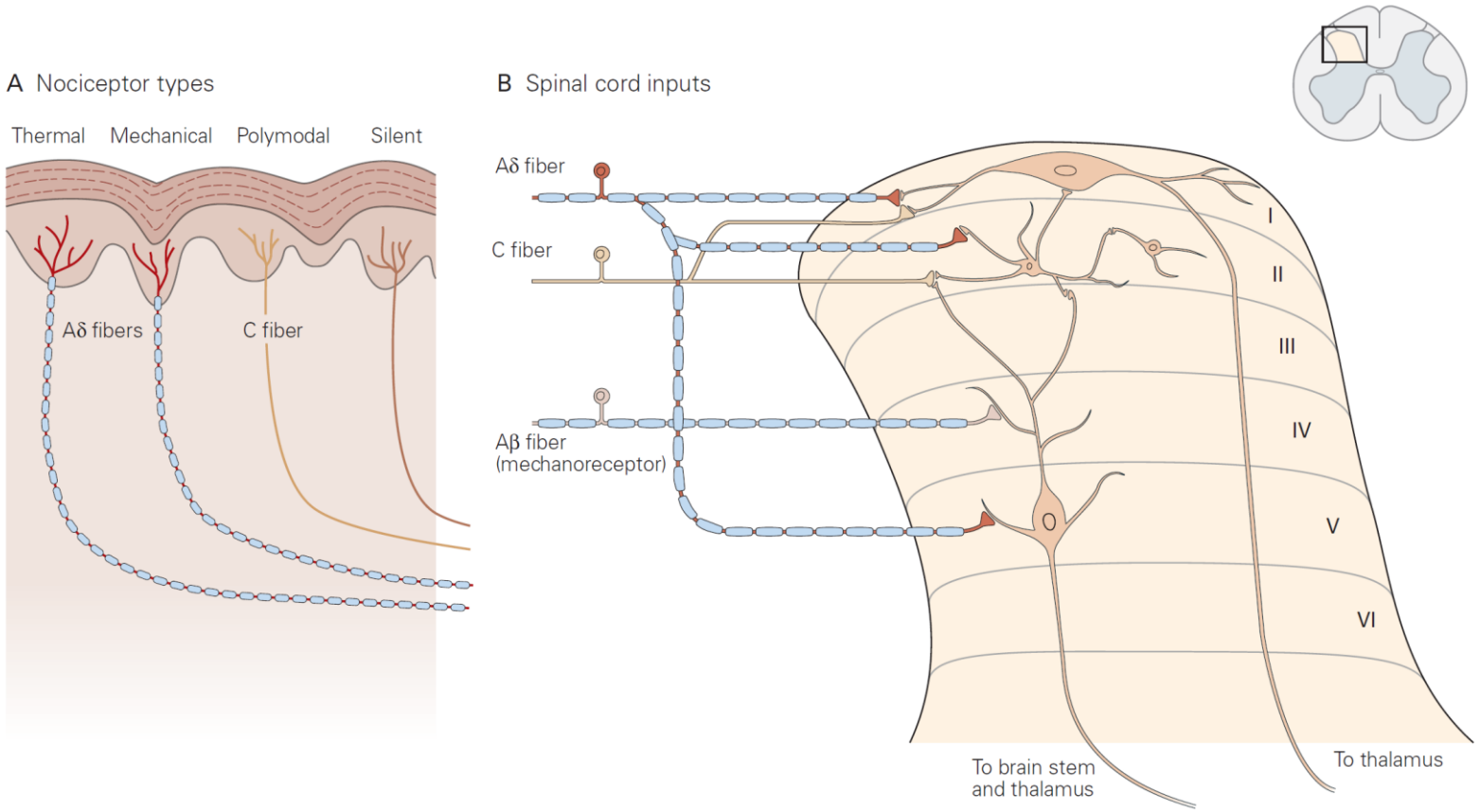
Spinal connections of nociceptive axons.



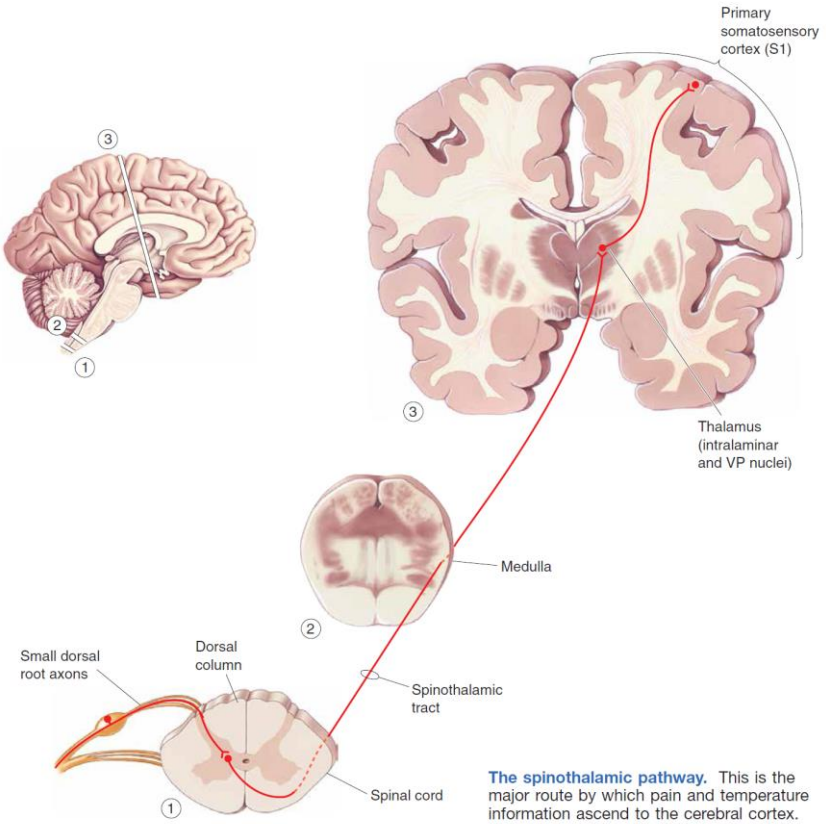
Referred pain: mixing of information from two sources of input



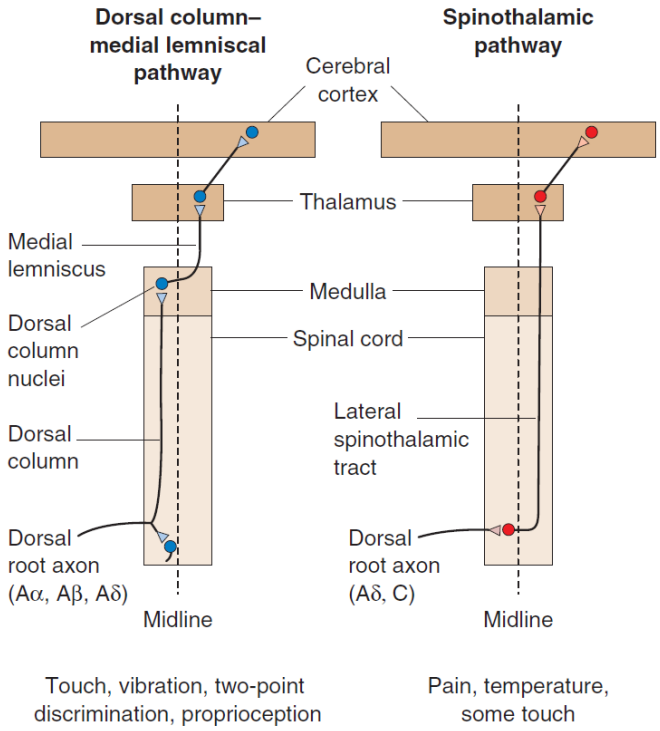
Nociceptive fibers terminate in the dorsal horn of the spinal cord



The spinothalamic pain pathway

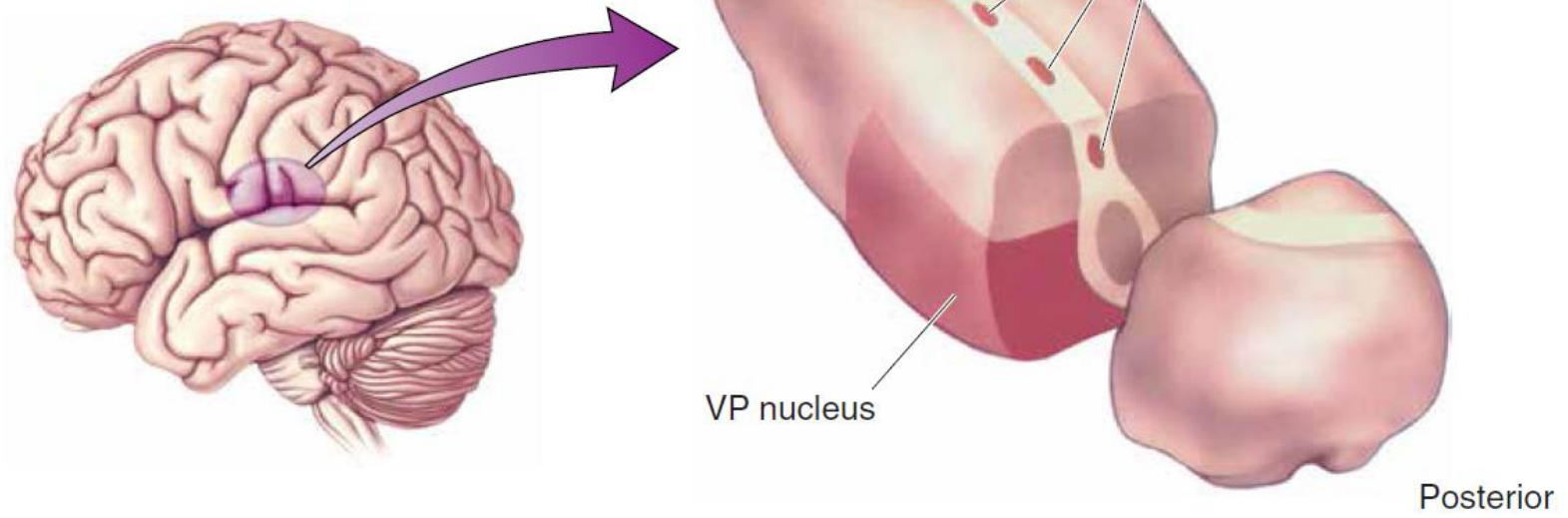


The spinothalamic pathway. This is the major route by which pain and temperature information ascend to the cerebral cortex.

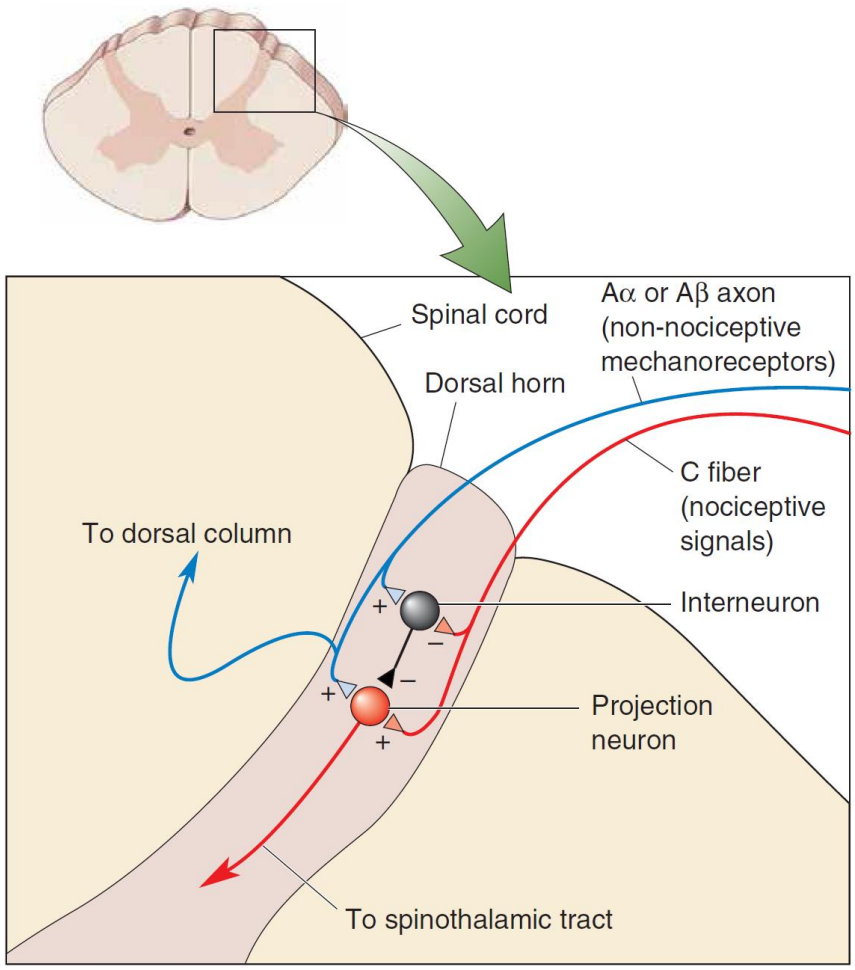


Somatic sensory nuclei of the thalamus

In addition to the **VP** nucleus, the **intralaminar** nuclei relay **nociceptive information** to a large expanse of the cerebral cortex.

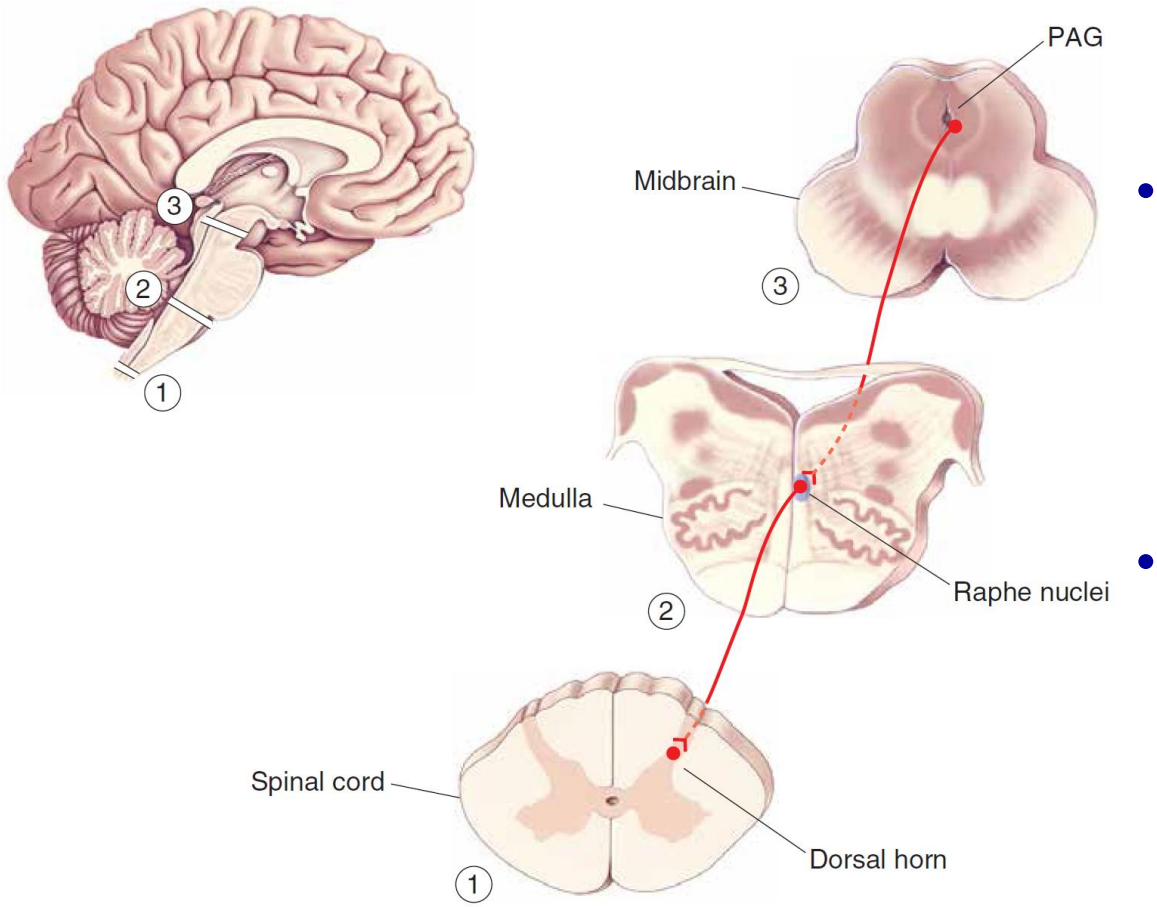


Afferent regulation of pain



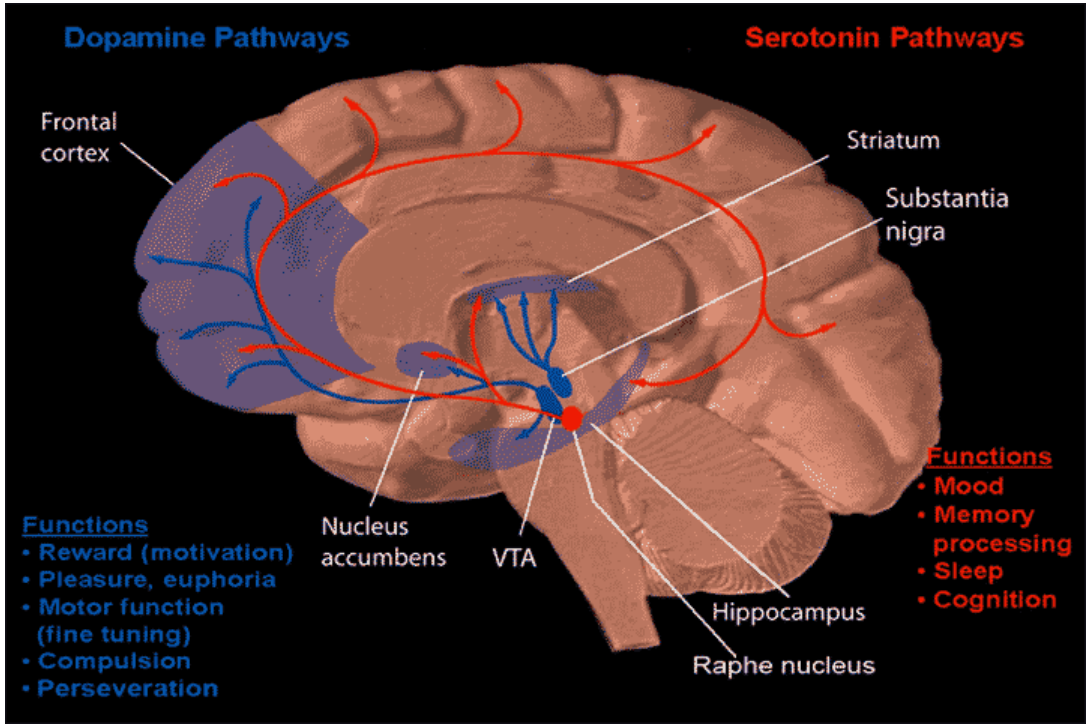
- Activity in the **pain axon** alone **maximally** excites the projection neuron,
- However, if the large **mechanoreceptive** axon fires concurrently, it activates the **interneuron** and **suppresses nociceptive** signals.
- **Melzack's and Wall's gate theory of pain.**

Descending pain-control pathways.

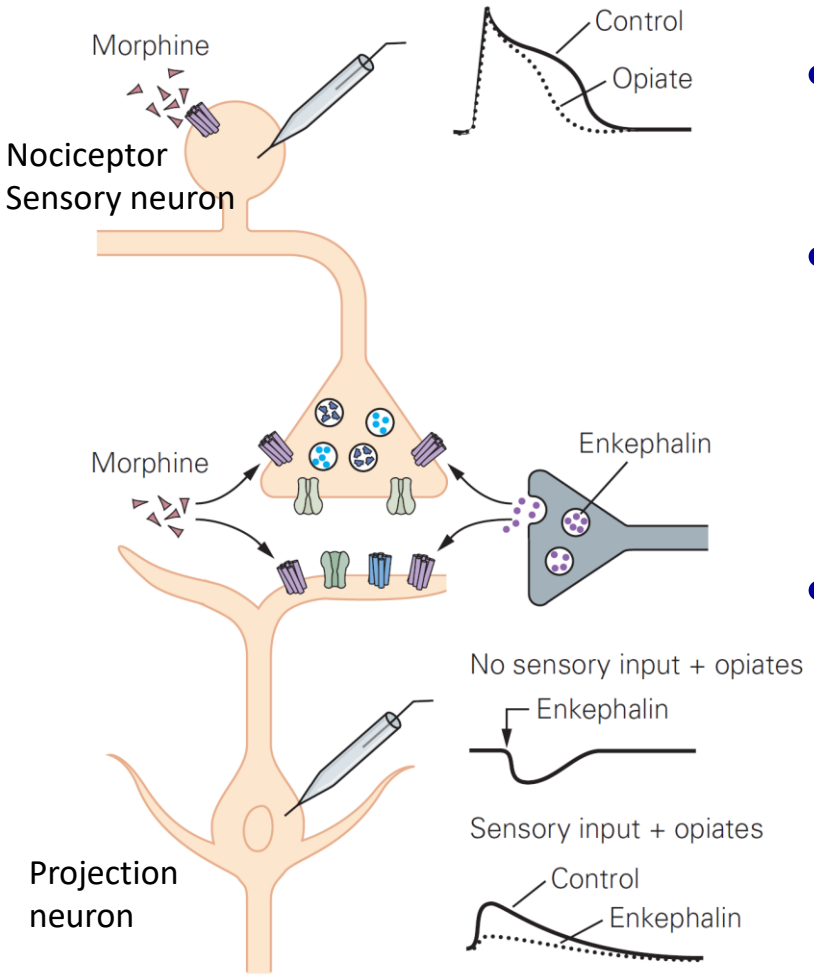


- A **variety** of brain structures, many of which **are affected by behavioral state**, can influence activity within the **periaqueductal gray matter** (**PAG**) of the midbrain.
- The PAG can influence the **raphe nuclei** of the medulla, which in turn can **modulate the flow of nociceptive** information through the dorsal horns of the spinal cord.

About raphe nucleus; the origin of serotonin



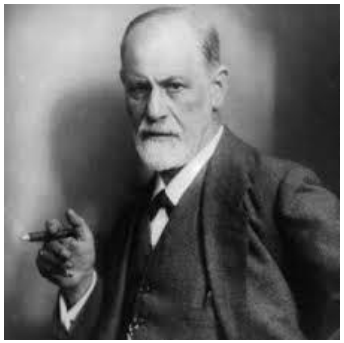
Morphine controls pain by activating opioid receptors



- The Endogenous Opioids (**endorphins**)
- Small injections of **morphine** or **endorphins** into the PAG, the raphe nuclei, or the dorsal horn can produce **analgesia**
- Extensive systems of **endorphin-containing neurons** in the spinal cord and brain stem prevent the passage of nociceptive signals through the dorsal horn and into higher levels of the brain where the perception of pain is generated

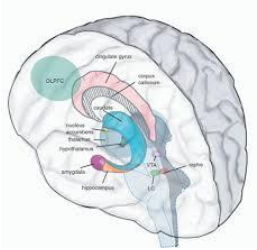
Unconscious process

- 1860, **Herman Helmholtz**:
  - He measured the conduction **velocity** of nerve impulse
  - By finding the **reaction time**, he found we need ***unconscious inference*** in our brain



- **Sigmund Freud** elaborated on Helmholtz's idea
  - much of mental activity is unconscious,

Our unconscious mental life is not a single process



- It has at least three component
  - Implicit unconscious: Helmholtz's *unconscious inference*
    - Implicit memory: a type of memory that underlies learning perceptual and motor skills
    - Striatum, cerebellum, amygdala
  - Dynamic part of unconscious :
    - Involves our conflict, repressed thoughts and sexual as well as aggressive urges
    - major focus of Freud's work
  - Preconscious unconscious
    - part of the unconscious that is most readily accessible to consciousness
    - organizing and planning for immediate actions
    - we now attribute to the prefrontal cortex

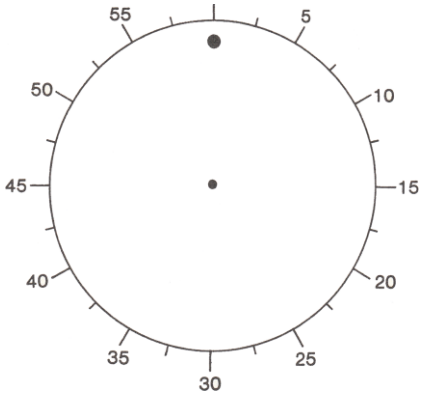
What is left for freedom of action?

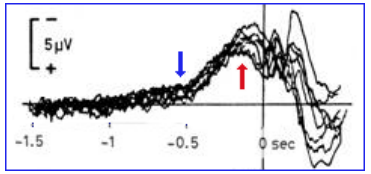
- Most things are unconscious thus what is the nature of free will?
- Benjamin Libet study ☺
- 1983:

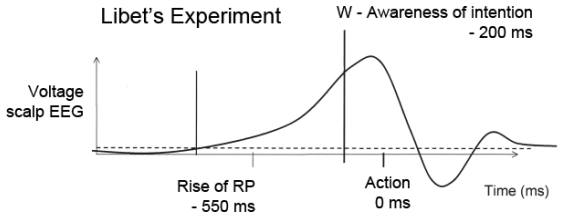
voluntary movement is preceded by a *readiness potential*

Readiness potential

- Small electrical response recorded from the surface of the skull that occurs approximately **one second before** the movement
- The subject was asked to **note the position of the moving dot** when he/she **was aware of the conscious decision** to move a finger or wrist
- We can predict a subject's desire to move a finger **before** the subject is aware of his own desire to move that finger!
- Thus what **we consider acts of free will** may have a **significant unconscious** step.
- Potential can be seen as early as 1.5 seconds before the action.







Is consciousness accessible to neurobiological analysis?

- Exploration of the nature of **spatial neglect** and **free will** → touches on one of the great issues of all science:

  the nature of consciousness

- How consciousness might be **explained in reductionist physical terms.**
- Neuroscience view:
  - ***Mind*** is a **set of operations** carried out by the **brain**
  - Consciousness is a **fundamental** property of mind → consciousness could be a **function** of brain
  - We must first **define consciousness in operational** terms.

- **Concepts** in neuroscience come form **philosophy**: learning, memory, . . . and then precisely define by science
- This approach **could even applied** for consciousness
- Consciousness is defined as a **state of self-awareness**,
- Three essential feature of consciousness:
  - Subjectivity
  - Unity
  - intentionality

Thomas Nagel

John Searle

Subjectivity

- **Awareness of self** that is the center of **experience**
- Experience **unique and private** world of sensation
- **Our experience** seems much **more real** than other experience
- Our sensation; moods, joys, disappointment, pain; is **direct** and other people sensation for us in **indirect**
- The aroma of lavender that I smell is identical to your experience of lavender → this **is not totally related to our sensory capability**
- If **sensory** capabilities were identical, it is also depend on **our personal history** → lavender may not produce same subjective sensation in each of us.

Main challenges

- How does our sensation, the conscious awareness, **arise from neural networks of the brain**?

- Is it possible to extract **objective characteristic for consciousness** ?

- One possible argue:
  - Objective understanding of experience **from same sense** (!)

Unity

- Our experience of the world **at any given moment** is felt as a **single unified experience**.

- All of various sensory modalities are **blended into single** experience.

- The simultaneous sense of different modalities in one experience and **role of attention**

Intentionality

- "The power of minds **to be about**, to **represent**, or to **stand for**, things, properties and states of affairs“

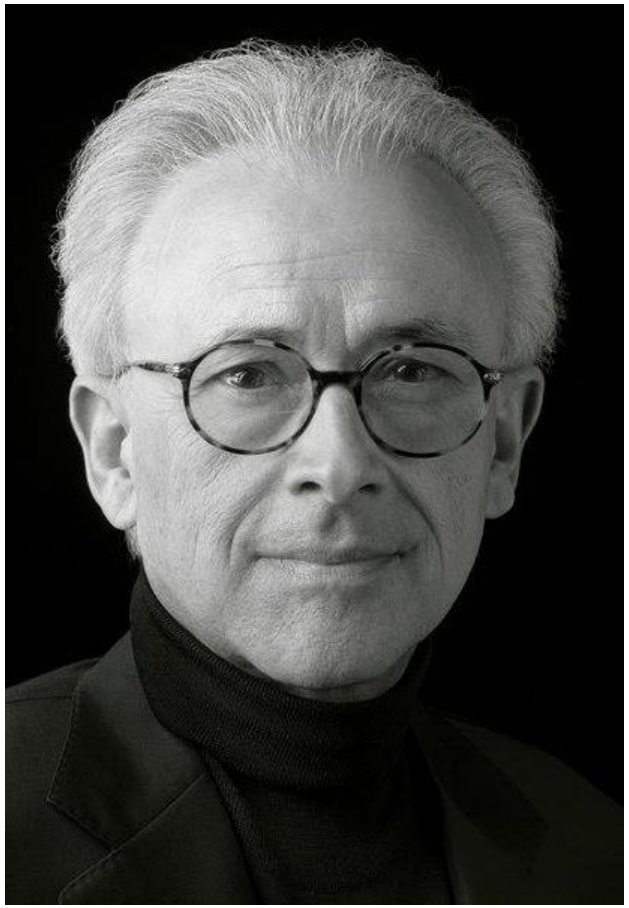
- Ability of the mind to form **representations**

- **Intention** is a mental state that represents a commitment to carrying out an action or **actions in the future**. Intention involves mental activities such as **planning and forethought**

amasio

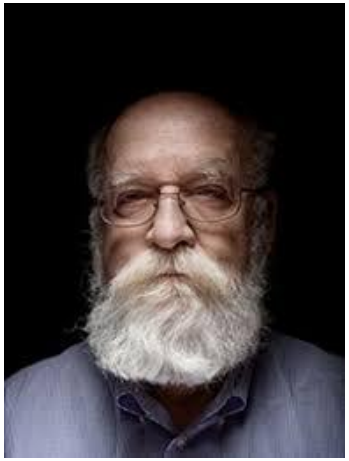
Distinguish between **primary** (or core) consciousness and **higher-order** (extended) consciousness

- Primary consciousness is an **awareness of objects** in the world, ability to form mental images of them. It is not **unique** to humans
- Higher-order consciousness involves a **consciousness of being conscious** and is uniquely human



Dualism and two groups in consciousness

- In **earlier** times, these three views lead to **dualism**
- Today, all philosophers of mind agree that what we call consciousness **derives from physical properties**
- Two group related to consciousness:
  - **First: Daniel Dennett**: there is **no problem** of consciousness. **Consciousness emerges quite simply from an understanding of neuronal activity**
  - Consciousness is the **continues phenomena** outcome of the **association area**.
  - **Second**: Francis Crick, Christof Koch, John Searle, Thomas Nagel, Antonio Damasio, and Gerald Edelman:
  - consciousness is a **discrete** phenomenon and issues of subjectivity, unity, and intentionality must be **confronted** if we able to understand how our experience is constructed.



Colin McGilm vs. Searl and Nigel

- **Colin McGilm** : consciousness is simply inaccessible to empirical study because of **limitations inherent in human** intelligence
  - Just as monkeys cannot understand quantum theory
- **Searle and Nagel** argue that consciousness ***is*** **accessible** to analysis but we have been **unable** to explain it because it is a **highly subjective** and **complex property of the brain** unlike any function of the brain, **we understand**

Subjectivity is the most difficult to analyze empirically (Searle argues)

- If we find the neurons in some one that are related to conscious attention:
  - Can we say that the firing of a group of neurons ***causes*** **a private subjective experience**?
    - When mother looks at her infant child the firing rate of cell in prefrontal concerned with face recognition cause conscious recognition?
  - We don't know how the firing of specific neurons lead to perception
  - How **ontological** objective phenomenon (spike of neurons) lead to **ontological** **subjective** phenomenon
  - Consciousness is **irreducibly** **subjective**

Nigel argues

- Because current science is **essentially a reductionist** approach to understanding phenomena it cannot address consciousness without **a significant change in method**
- Object to-object reductions are not problematic
  - We understand how the properties of given type matter comes form the molecule of which is made
  - What we lack are **rules for extrapolating subjective experience** from the **physicochemical** properties of interconnected nerve cells.
  - We **dont know** the **element** of subjective experience

"What Is it Like to Be a Bat?" (1974)

Discovery of the elementary components of subjective consciousness

- Nigel argue that, lack of insight into the **elements** **of subjective experience** **should not prevent** us from discovering rules that **relate conscious** phenomena to cellular processes in the brain.
- Knowledge needed to think about a more fundamental type of **analytical reduction** from something subjective (experience) to something objective (physical)-can be gained only through the **accumulation of cell-biological information**
- Nagel argues, **may require** a **revolution** in **biology** and most likely a complete transformation of **scientific thought**

Neurobiological research on cognitive processes does not depend on a specific theory of consciousness

- Steven Weinberg:

I don't see how anyone but George will ever know how it feels to be George. On the other hand, I can readily believe that at least in principle we will be able to explain all of George's behavior reductively, including what he says about what he feels, and that consciousness will be one of the emergent higher-level concepts appearing in this equation.

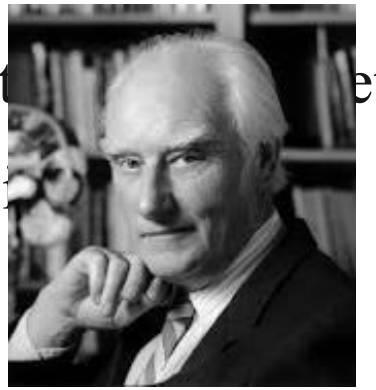
- Neuroscience has made a considerable **progress** in neurobiology of sensory perception without **having to account for individual experience**. It dose not need to resole the question of whether each of us sees the same.
- We found the **correlation of physical properties** response of neurons.
- we **do not understand** is the step from action potentials to awareness of an object

Neural correlates of consciousness

- The subjective nature of perception **does not prevent** **one person from objectively studying what another person perceives**.
- Crick and Koch:
  - **First step** in the analysis of consciousness is to find the

of consciousness, t et of

give rise to a consc



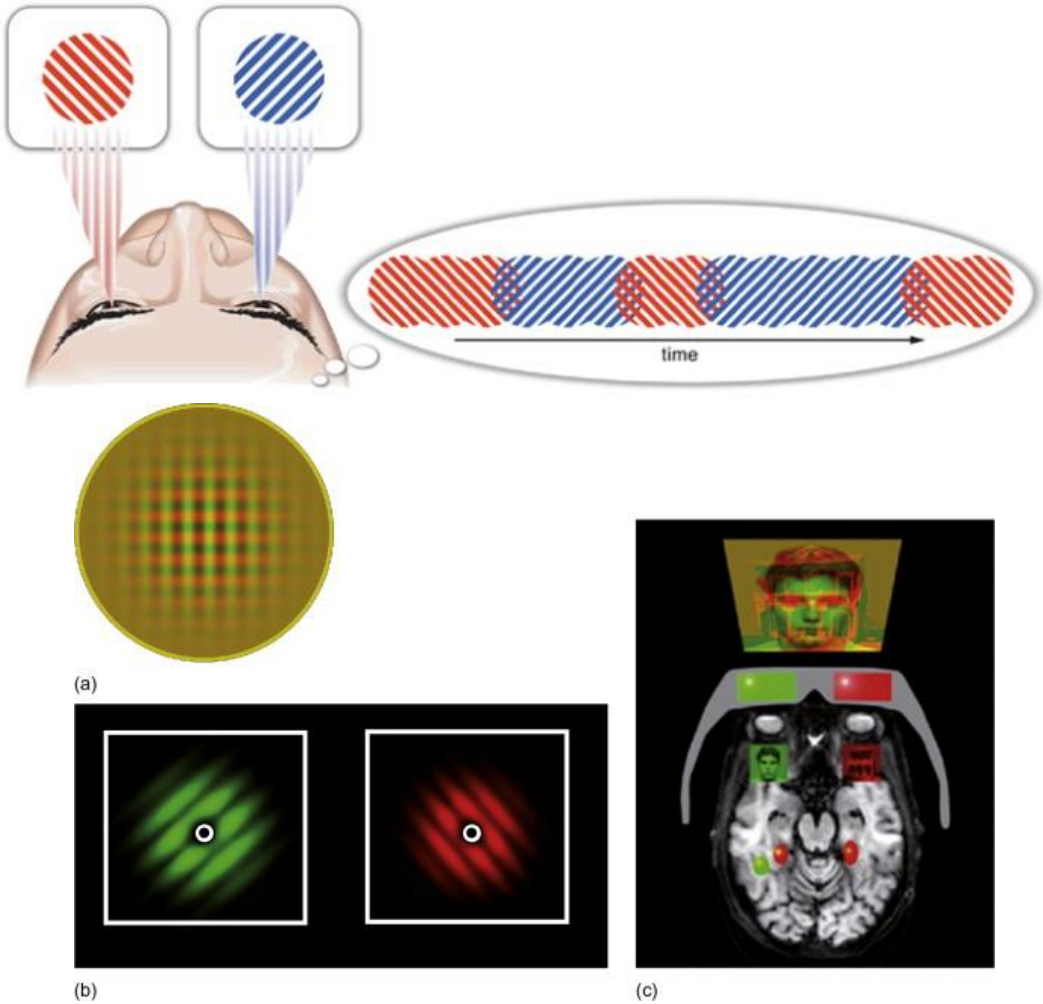
Gerald Edelman and Stanislas Dehaene vs. Crick and Koch


- **Gerald Edelman and Stanislas Dehaene :** neural correlates of consciou **unlikely to be localized** but rather widely **distributed throughout** the o and thalamus.
  - Extensive **evidence** of massive feedforward broadcasting as well as, feedback or recursive connections between cortical areas
- **Crick and koch:** most elementary neural correlates of consciousness are likely **to involve only a small set of neurons**, and therefore one should be able to determine the neural circuits to which they belong.
  - Because at any moment we can be conscious of one of a large variety of sounds, smells, and objects as well as actions, **consciousness must involve modulatory control** over a variety of neural systems.
  - **Binocular rivalry and selective attention**

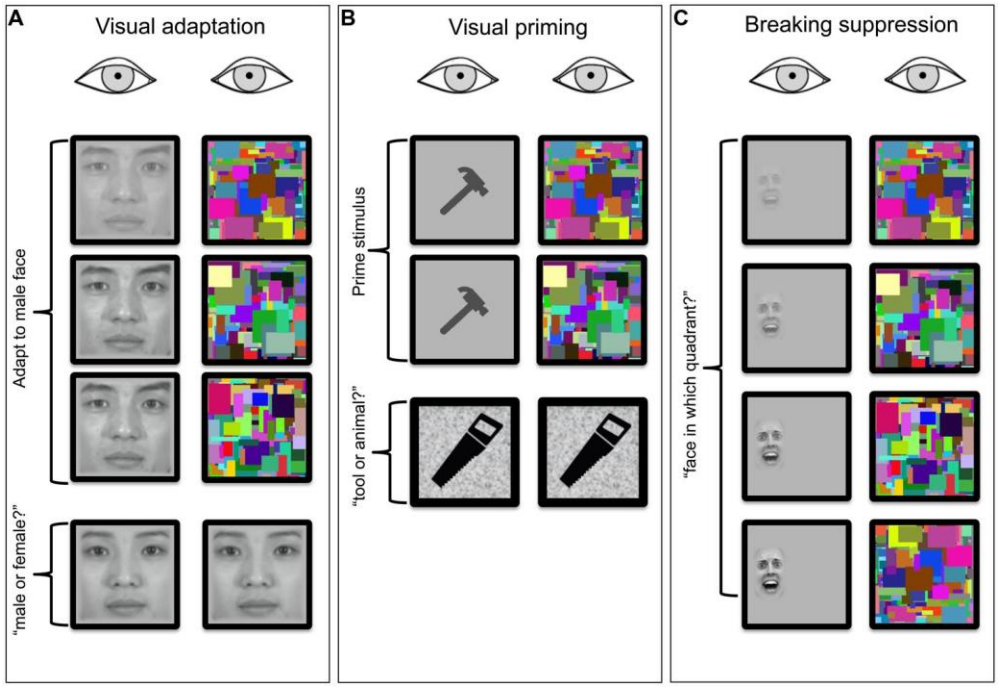
Studies of binocular rivalry have identified circuits that may switch unconscious to conscious visual perception

- Subject's perception **alternates spontaneously** from one monocular view to the other.
- **Three** sets of cortical areas are recruited
  - Ventral **visual pathway** for perception of object
  - **Parietal** and **frontal** regions: visual **attention to space**
- Nikos logothetis in single cell study showed:
  - Rivalrous stimuli in the two halves of the visual field is resolved late in the ventral pathway, in the **inferior temporal cortex** and the lower layers of the **superior temporal sulcus**

stereoscope


time
(a)
(b)
(c)

Continuous flash suppression



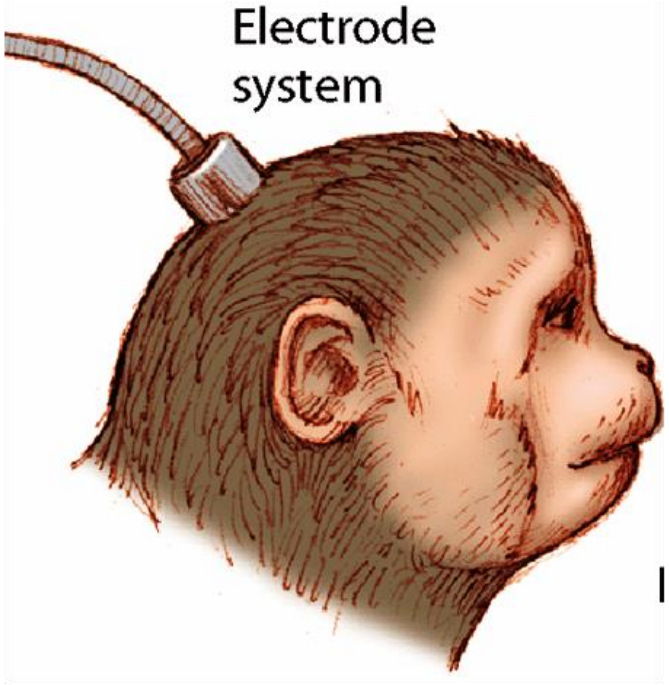
Selective attention to visual stimuli can be studied on the cellular level in nonhuman primates

- **Selective attention** in vision is good **pilot** for study of **consciousness**
- Williams James first noted in his ***Principles of Psychology*** (1890):

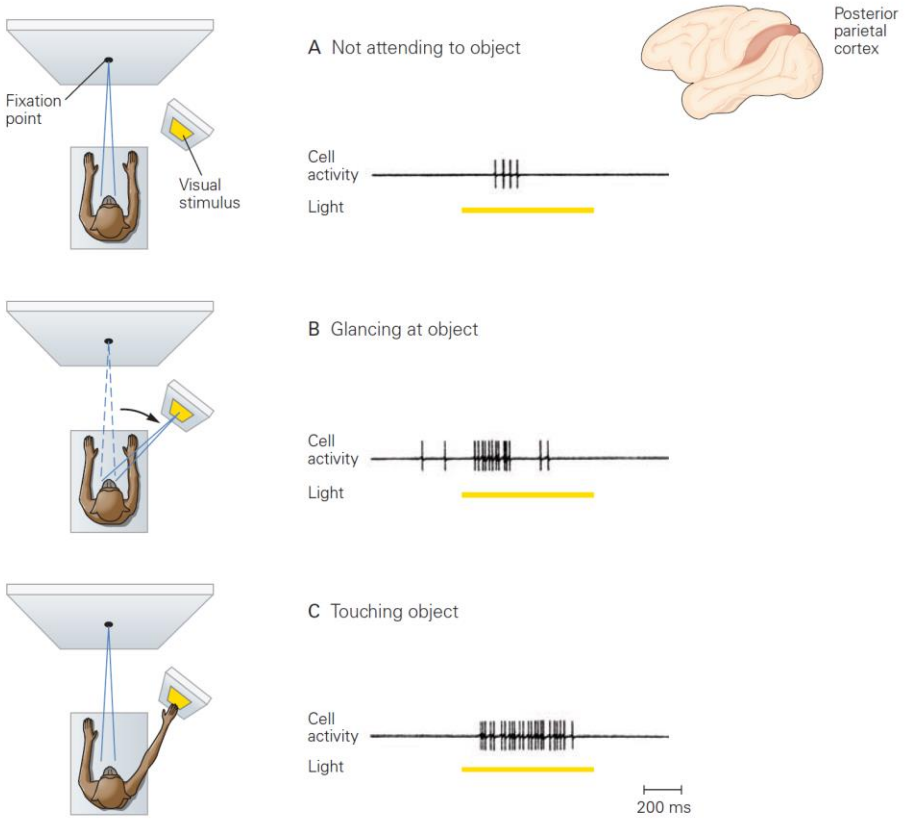
> Millions of items . . . are present to my senses which never properly enter my experience. Why? Because they have no interest for me. My experience is what I agree to attend to. . . . Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects of trains of thought. Focalization, concentration of consciousness, are of its essence. It implies withdrawal from some things in order to deal effectively with others.

Intracranial and “single” Unit

- Single electrodes may pick up **action potentials** from a single cell
- An electrode may pick up the signals from several nearby cells
  - **Spike-sorting** attempts to isolate individual cells



Neurons in the posterior parietal cortex of a monkey respond more vigorously to a stimulus when the animal is attentive to the stimulus



- The response of the neuron is **independent of how the animal attends** to the stimulus.
- parietal cortex makes connections with structures in the prefrontal cortex that are **involved** in the **planning and execution** of movements of the eyes and hands.

Final argue by Kandel

- Eventually be in a position to meet **searle's and nagel's** higher demands: to **develop a theory of the correlations we discover empirically**, to state the **laws of correlation** between neural phenomena and **subjective** experience.