Brain Resource Creation Workshop: Chapter 2 - Senses and Perception

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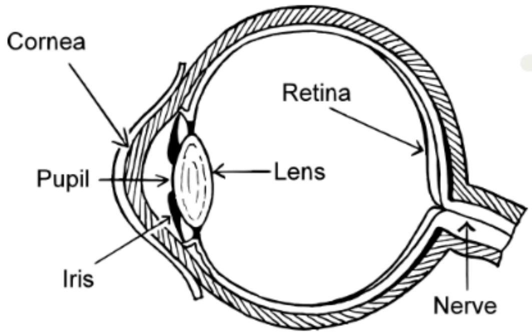
Simply Neuroscience

VISION



- Involves 30% of human cerebral cortex

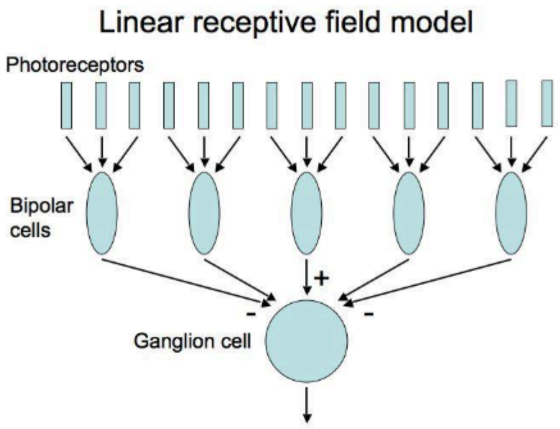
- Light passes through **cornea** (initial focusing) → enters eye (**pupil**)
  - **Iris** regulates amount of light entering (changes pupil size)
  - **Lens** bends light to focus on inner eyeball surface (**retina**)
  - Signals get processed by **retina**'s specialized cells and then travel to other parts of brain for further integration & interpretation
    (via **optic nerves**)

The Three-Layered Retina

- Home to **3 TYPES OF NEURONS** organized into several layers
    - **Photoreceptors** - light-sensitive (rods, cones); located in most peripheral region of retina; 125 million per human eye → turn light into electrical signals
        - **Rods** (95% of photoreceptors) allow you to see in dim light; **Cones** (red, green, blue) pick up fine detail in color → can see color spectrum; most densely packed in **fovea** (red & green)
            - **Macula** (area around fovea) → crucial for reading & driving
                - *Macular [photoreceptor] degeneration* = leading cause of blindness (55+)
    - **Interneurons** <u>and</u> **Ganglion cells** - process and relay info from photoreceptors

The Three-Layered Retina

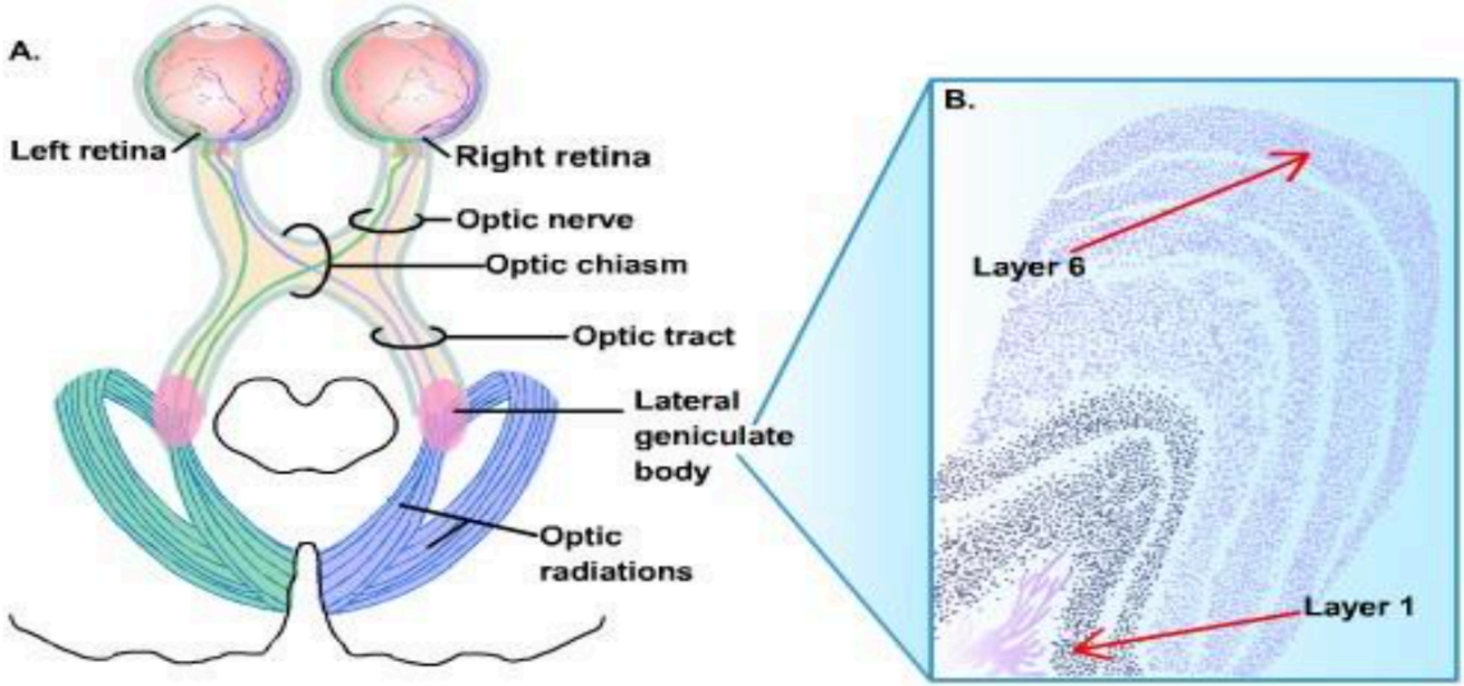
- Neurons in 3 retina layers receive input from cells in preceding layers; number of inputs varies across retina.
    - Macular region: input from cones → interneurons → ganglion cells = resolution of fine details
    - Margins of retina: photoreceptor cells → ganglion cells = peripheral vision (less detailed)
- Receptive field = portion of visual space providing input to single ganglion cell



<u>How is Visual Information Processed?</u>

- Light passes through the optical lens and hits retina at back of eye
- Receptor field of ganglion cell is **activated** if the center region is hit, but **inhibited** if the donut-shaped area surrounding the center is hit
  - Responds **weakly** if center <u>and</u> donut area hit
- Receptors in retina transform light to electrical signals
- Electrical signals carry info via optic nerves to the brain's visual processing centers
  ⇒ **Optic chiasm** - crossover junction where both eyes' nerve fibers converge: left side of both retinas → left side of brain, right side of both → right side of brain
- Then to the lateral geniculate nucleus (thalamus) → Primary visual cortex (rear of brain)

How is Visual Information Processed?

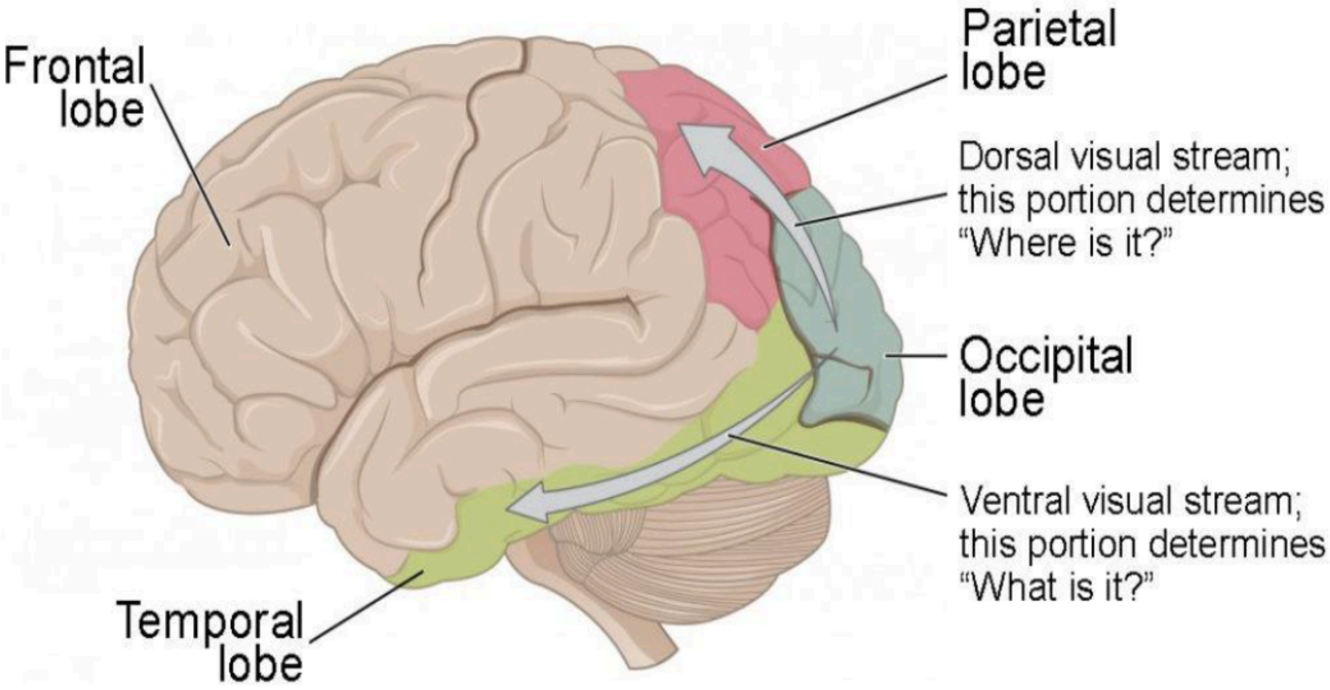


Visual Cortex: Layers, Angles, and Streams

- **Primary visual cortex**: neural tissue found on occipital lobe (brain)
- **Middle layer:** receives messages from thalamus; preserves retina's visual map; contains more complex receptive fields which have register stimuli shaped like bars/edges
- New processing streams from these layers pass info to other parts of visual cortex
- Visual information combined in other areas = more complex/selective receptive fields (e.g. higher level neurons only respond to specific objects or faces)

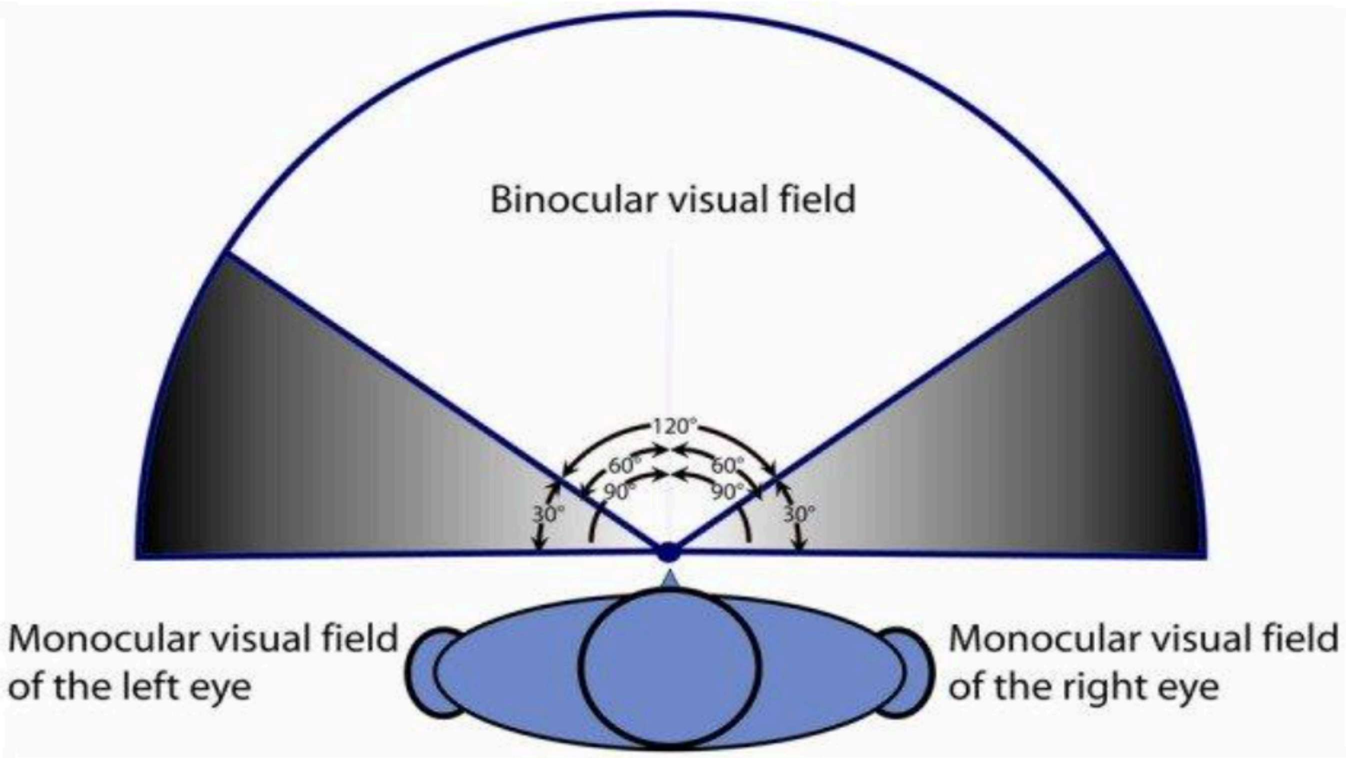
<u>Visual Cortex: Layers, Angles, and Streams</u>

- Visual signals are fed into several parallel but interacting processing streams
  - *Dorsal* aka "where" stream (up toward parietal lobe)
  - *Ventral* aka "what" stream (down to temporal lobe)
- **Dorsal or "Where" stream**: integrates info about shape, color, etc. with memories and experiences to <u>recognize</u> something with specificity
  - Ex: Recognizing a dog as your neighbor's and not yours.
- **Ventral or "What" stream** → combine spatial relationships, motion, and timing to create an <u>action</u> plan (w/o conscious thought)
  - Ex: Yelling "STOP!" without thinking


Frontal lobe
Parietal lobe
Dorsal visual stream; this portion determines "Where is it?"
Occipital lobe
Ventral visual stream; this portion determines "What is it?"
Temporal lobe

Eyes Come in Pairs

- **Binocular Vision** = seeing with two eyes → perceive depth (3D) through angles in which the eyes' visual fields overlap & both eyes are equally active and properly aligned
- Two eyes = larger visual field to be mapped onto primary visual cortex
- Crossing-over of nerve fibers lead to signals from left **vf** → right side of brain (vice versa).
    - Cerebellum (movement & touch): information processing from opposite side of body
- People with **strabismus** (crossed eyes) miss out on depth perception.



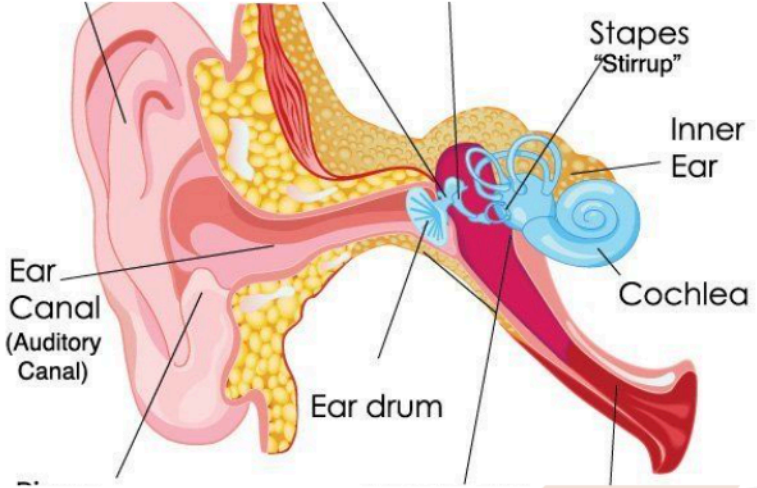
Binocular visual field
120°
60°
60°
90°
90°
30°
30°
Monocular visual field
of the left eye
Monocular visual field
of the right eye

Treating Visual Disorders

- Strabismus patients eventually favor one eye, lose vision on the other = blindness
- Blindness is also often caused by loss of function/death of photoreceptors and genetic defects
- **Possible treatments**: gene therapies, manual transmission of electrical signals directly to brain vs. restoration of photoreceptors

Hearing

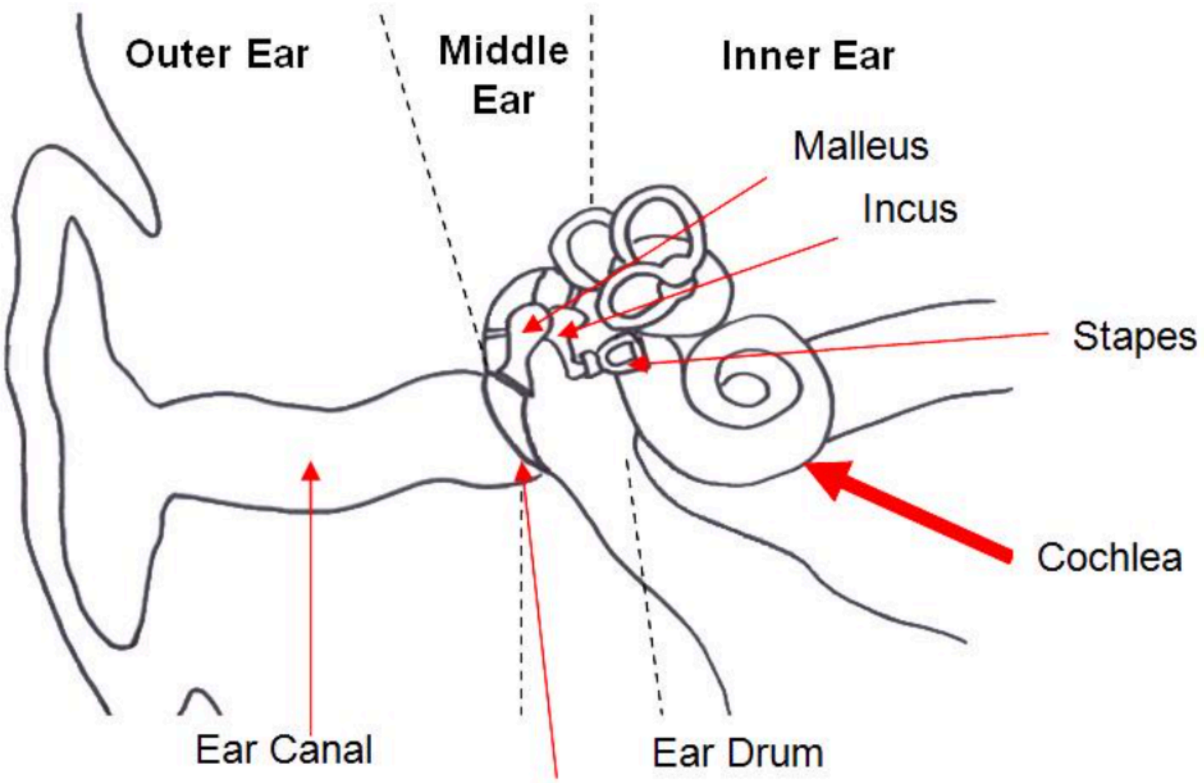
- ***Auditory system***
  Picks up various qualities of detectable signals of sound: **pitch, loudness, duration, location**
- Analyzes complex sounds, breaks them into separate components/frequencies



Can You Hear Me Now?

1. Sound (air pressure waves) reaches pinnae of ears, funneled to ear canals to reach eardrum (tympanic membrane)
2. Eardrum vibrates in response
3. Vibrations sent to 3 sound-amplifying bones - hammer, anvil, stirrup
4. Stirrup acts as piston, pushes on oval window (separates air-filled middle ear from fluid-filled snail-like cochlea)
5. Oval window converts mechanical vibrations into pressure waves in cochlea
6. Waves transduced into electrical signals by hair cells (specialized receptor cells)

Can You Hear Me Now?



From Pressure Wave to Electrical Signal

- Elastic basilar membrane (inside cochlea) “tunes” to different frequencies/pitches.
- Cochlea fluid ripples = basilar membrane moves; vibrates to higher pitches (screech) near oval window and to lower pitches (bass drum) in center
- Rows of sensory hair cells found on top of basilar membrane. When it vibrates, they bend against tectorial membrane: physical movement → electrochemical signal
- Auditory nerve excited → sends electrical signals to brain stem
- Thalamus (brain’s relay station for incoming sensory information) sends info → auditory part of cerebral cortex

Making Sense of Sound

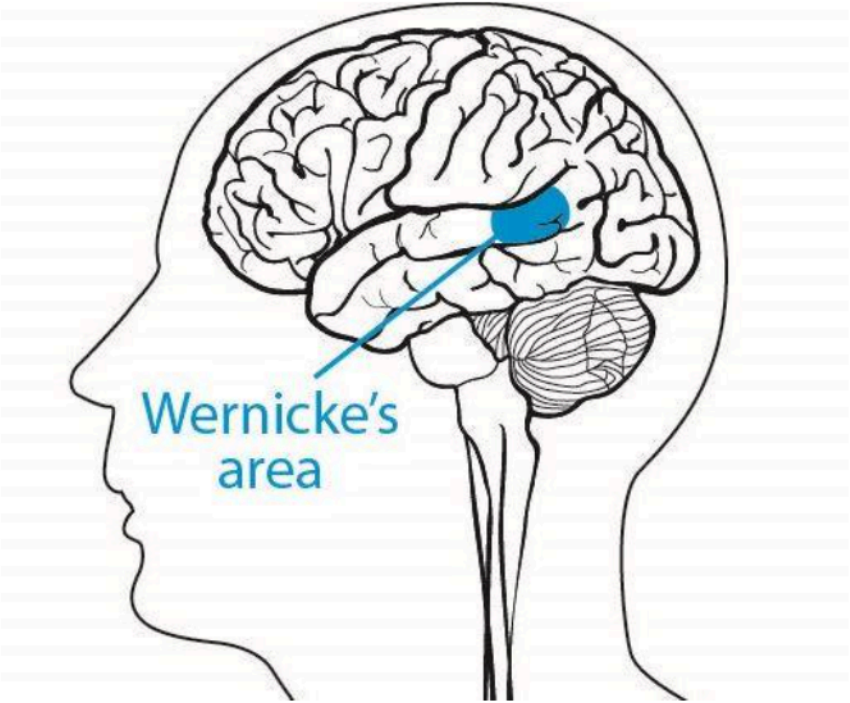
- Sound direction is computed by the brainstem and thalamus using information from both ears (on the way to cortex)

- Frequency map of basilar membrane maintained throughout

- Cortical neurons respond to **intensity, duration,** and **changes in frequency**.
    - Others are selective for complex sounds or specialize in various tone combos
    - Higher-level neurons can process **harmony, rhythm,** and **melody** = voice/instrument

- Left side of brain = understanding and producing speech
    - Someone with damage in **Wernicke's area** (region in left auditory cortex) can hear speech but can't understand what is said

Making Sense of Sound



Treating Hearing Loss

- Mostly caused by **loss of hair cells**, which can't regrow
  Current research is looking for ways that could involve **neurogenesis** - replacement of damaged hair cells!

Taste and Smell

- Gustation (taste) and olfaction (smell)
- Contribute to how food tastes
- Important for survival → hazardous substance detection
- Cells processing taste and smell are exposed to outside environment = vulnerable = regularly regenerate
- Olfactory receptor neurons are the only ones that are continually replaced throughout our lives!

From Molecules to Taste

- Molecules set free when you chew/drink are detected by **taste/gustatory cells** within **taste buds** (tongue, roof & back of mouth)
- 5,000 to 10,000 taste buds (start to lose by age 50) x 50-100 sensory cells: receptive to **sweet, sour, salty, bitter, umami** *(savory)* taste qualities
- All tastes are detected ACROSS the tongue, not limited to specific regions
- Stimulated taste receptor cells send signals (through 3 cranial nerves: facial, glossopharyngeal, vagus nerves) to taste regions in brain stem → routed through thalamus → gustatory cortex (frontal lobe) & **insula** (specific taste receptors)

<u>From Molecules to Smell</u>

1. Odors enter the nose (air currents) → bind to specialized olfactory cells on mucous membrane inside nasal cavity
2. Axons of sensory neurons enter 2 **olfactory bulbs** (1 per nostril)
3. Info travels to olfactory cortex

- **Smell** = only sensory system that sends info directly to the cerebral cortex <u>WITHOUT</u> first passing through the thalamus
- 1,000 different types of olfactory cells, can identify 20x as many smells!

From Molecules to Smell

- Tips of olfactory cells equipped with hair-like **cilia** receptive to odor molecules → various unique combinations of olfactory activity patterns
  Research: People can identify odors as quickly as 110 ms after first sniff!
- Size of olfactory bulbs and neuron organization change over time
  Olfactory bulbs in rodents & primates can generate new neurons throughout life (**neurogenesis**)

Combining Taste and Smell

- Sense of smell adds great complexity to flavors we perceive; taste perceptions are particularly enhanced when exposed to combinations of familiar tastes & smells
- Taste & smell info appear to converge in several central brain regions
- Some neurons in inferior frontal lobe that selectively respond to both senses
- Sensitivity to taste & smell loses over time; receptors are non-replaceable.
  Possible treatment: Stem cell therapies

TOUCH and PAIN

Somatosensory system

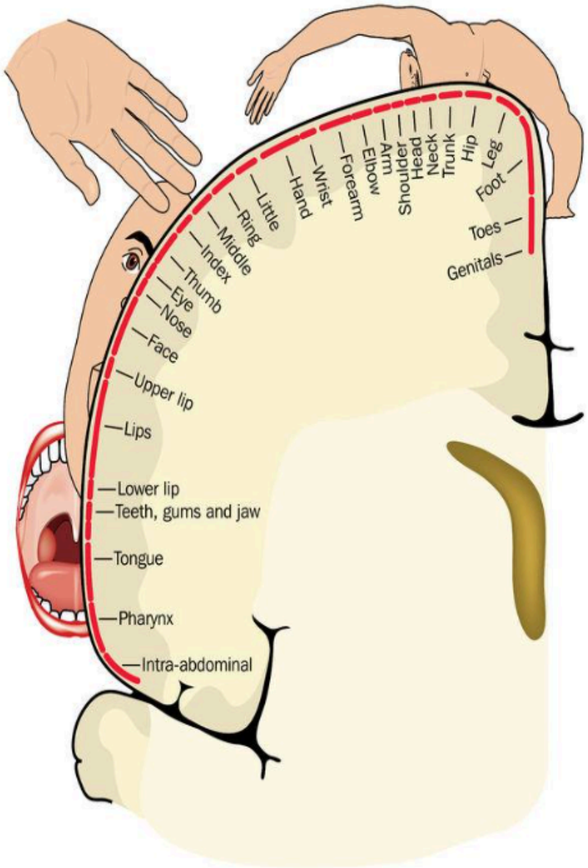
- Light touch, pressure, vibration, temperature, texture, itch, pain, etc.
- Perceived with various types of touch receptors w/ nerve endings located in different skin layers
- Touch receptor signals → sensory nerve fibers → thalamus → **somatosensory cortex** → translation into touch perception
  - Quick travel along A-beta fibers (thick) or slow travel along C fibers (thin)

Cortical Maps and Sensitivity to Touch

- Somatosensory info from all body parts spread onto cortex in the form of a **topographic map** curling around brain
- Very sensitive body parts stimulate much larger cortex regions > less sensitive body parts
- Sensitivity to tactile & painful stimuli depends on number of receptors per unit area <u>and</u> distance between them (more, closer = more stimulation)

  Measured using **two-point discrimination** - minimum distance between 2 points on skin that a person can identify as distinct stimuli vs. single one

Cortical Maps and Sensitivity to Touch



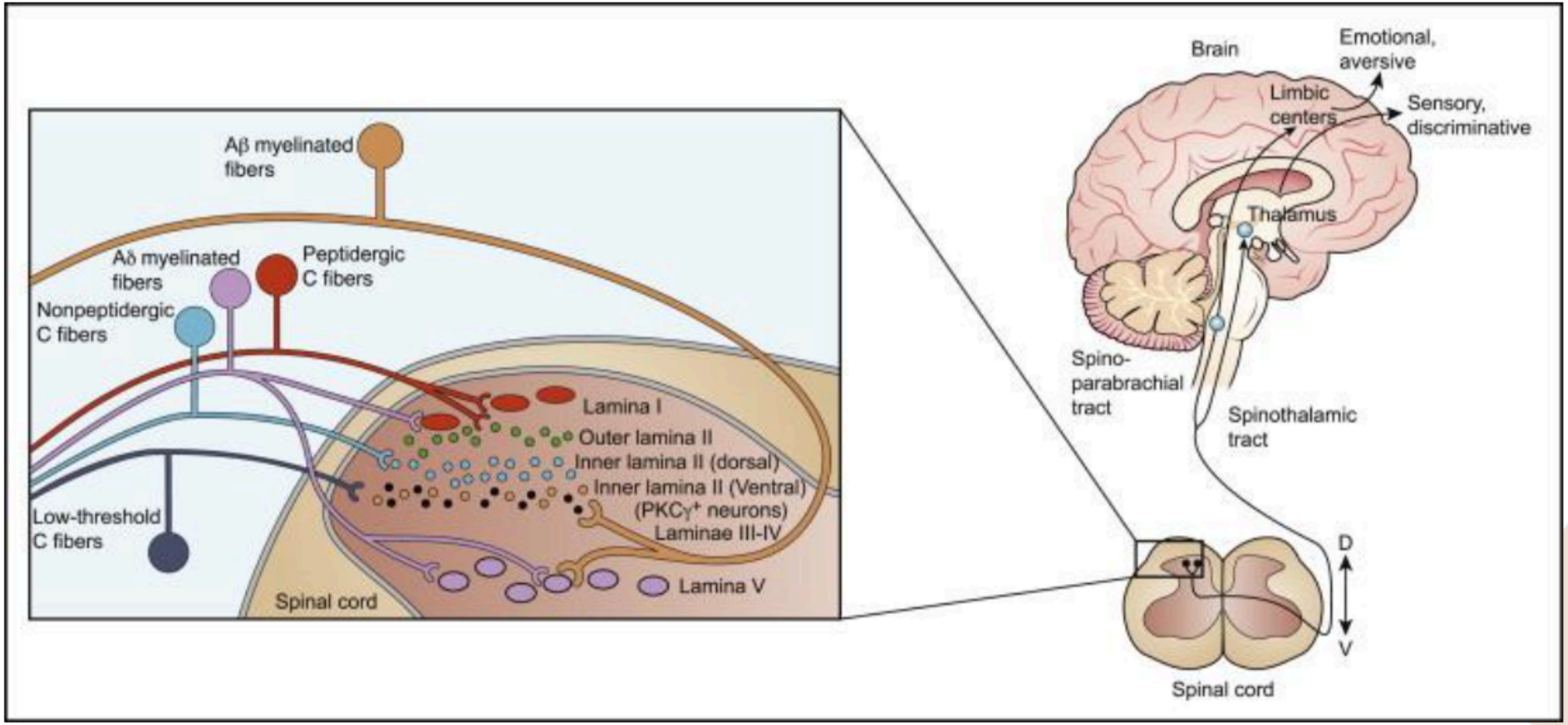
Pain and Itch Signals

- **Pain = both a sensory and emotional experience**
  - **Sensory** component signals tissue damage or potential for damage
  - **Emotional** component makes experience unpleasant & distressing
- Pain is a **warning signal**: something's wrong with your body
- Pain occurs when **nociceptors** respond to stimuli that can cause tissue damage (e.g. thermal, mechanical, chemical - heat/cold, wounds, toxins/venom, spicy food)
- Some types of nociceptors respond only to chemical stimuli that cause itchiness. (Ex. histamine receptors → skin irritation, bug bites, allergies)

Sending and Receiving Messages

- Pain & itch messages → small A-delta fibers (with aid of myelin sheath = faster) & smaller C fibers = *immediate, sharp pain* → spinal cord → brain stem → thalamus (ascending pathway) → cerebral cortex → conscious experience
- Brain has **no opportunity** to change how it responds to these messages
- Unmyelinated C fibers transmit pain messages more slowly = dull and diffuse pain sensation, hard-to-pinpoint origin

Sending and Receiving Messages



Pain Management

- Degree of pain depends on **stimulus strength, person's emotional state,** and **setting of injury**
  Once in cortex, pain messages are sent to brain stem region (**periaqueductal gray matter**) that activates descending pathways that modulate pain → send messages to networks → release **endorphins** (opioids) or adrenaline to intercept pain signals and regulate/reduce pain
- **No single brain area is responsible for perception of pain and itching.**
- Treatments (e.g. **cognitive behavioral therapy**) target emotional component of pain rather than stopping the stimulus itself.

We hope you enjoyed the workshop!

Any questions?

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