



The Brain, Biology and Cognition (BBC)

Lecture 4: Mechanisms of perception: Hearing, touch, and attention.

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Principles of Sensory System Organization



- **Organisation of other sensory systems is similar to that of vision.....**
- **The sensory areas of the cortex are considered to be of 3 different types:**
- **Primary cortex** – Main input from thalamic relay nuclei
 - E.g., striate cortex receives input from the lateral geniculate nucleus
- **Secondary** – input mainly from primary and other secondary cortex areas within the sensory system
- **Association** – input from more than one sensory system, usually from secondary sensory cortex

Principles of Sensory System Organization



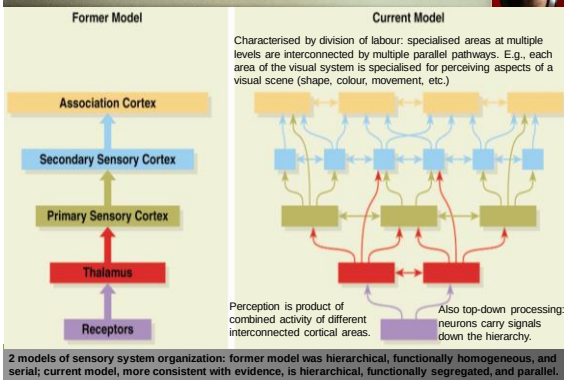
- **Interactions among these are characterized by three major principles:**
- 1. **Hierarchical Organization.....**
 - **Specificity** and **complexity** increases with each level through the system.
- Each level of a sensory hierarchy receives most input from lower layers and then adds another level of analysis before passing it on up the hierarchy.
- General process of perceiving is split in to two phases
 - **Sensation** – detecting a stimulus
 - **Perception** – integrating/understanding the stimulus

Principles of Sensory System Organization



- 2. **Functional Segregation exists in the system** – distinct functional areas exist within a level, and specialize in different kinds of analyses.
- 3. **Parallel Processing exists** – simultaneous analysis of signals along different pathways of a network.
 - Two types of parallel streams exist:
 - One capable of influencing behaviour by engaging conscious awareness
 - Another capable of influencing behaviour without conscious awareness

Principles of Sensory System Organization



Auditory System



- Function of auditory system is to perceive sound
- Natural sounds are complex patterns of vibrations of air molecules that stimulate the auditory system
- We hear molecule vibrations between 20-20,000 hz
- A Fourier analysis (mathematical procedure) breaks natural sounds down into sine waves
- Our system can then understand the sound through a complex relationship between the natural sound and perceived frequency



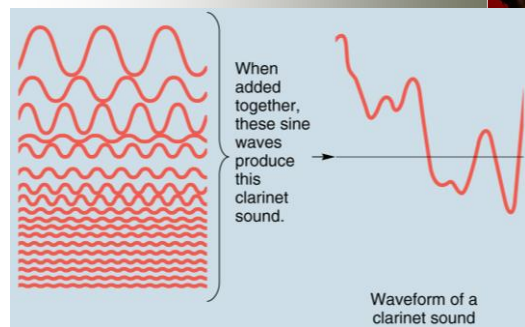
Principles of Sensory System Organization



Physical Dimension	Physical Stimulus	Perceptual Dimension
Amplitude		Loudness
Frequency		Pitch
Complexity		Timbre

The relation between the physical and perceptual dimensions of sound.

Principles of Sensory System Organization

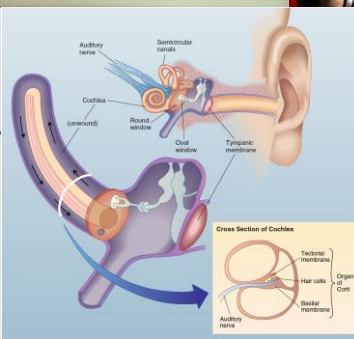


The breaking down of a sound—in this case, the sound of a clarinet—into its component sine waves by Fournier analysis.

The Ear

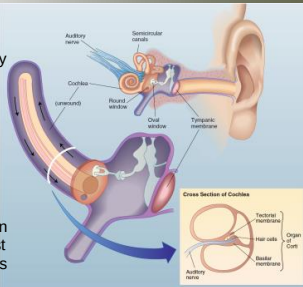


- Sound waves enter the auditory canal of the ear and then cause the tympanic membrane (the eardrum) to vibrate
- This sets in motion the bones of the middle ear, the ossicles, which trigger vibrations of the oval window
- Sound wave > eardrum > ossicles (hammer (malleus), anvil (incus), stirrup (stapes)) > oval window
- Vibration of the oval window sets in motion the fluid of the cochlea
- The cochlea's internal membrane, the organ of Corti, is the auditory receptor organ



The Ear

- Each pressure change at the oval window travels along the organ of Corti as a wave.
- Corti is composed of:
 1. Basilar membrane – auditory receptors (hair cells) are mounted here
 2. Tectorial membrane – rests on the hair cells
- Stimulation of hair cells triggers action potentials in the auditory nerve
- Tonotopic (frequency) organization of the basilar membrane and most other auditory system components



From the Ear to the Primary Auditory Cortex

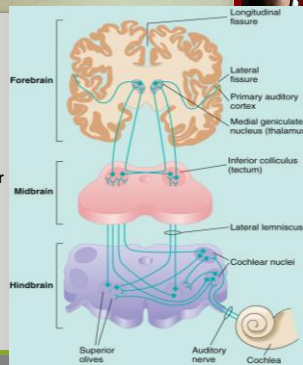
The axons of each auditory nerve synapse in the ipsilateral cochlear nuclei

From there, many projections lead to the superior olives on both sides of the brain stem

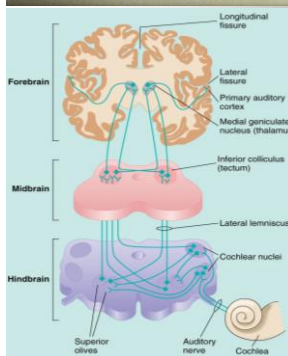
From there, axons project via the lateral lemniscus to the inferior colliculi

Axons then project from the inferior colliculi to the medial geniculate nuclei of the thalamus

Thalamic neurons then project to the primary auditory cortex



Subcortical Mechanisms of Sound Location



The lateral and medial superior olives react to differences in what is heard by the two ears

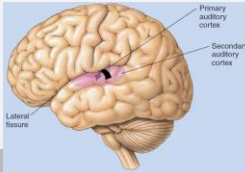
- Medial – arrival time differences
- Lateral – amplitude differences

Both project to the superior colliculus

- The deep layers of the superior colliculus are laid out according to auditory space, allowing location of sound sources in the world; the shallow layers are laid out retinotopically

Auditory Cortex

- Auditory cortex located in temporal lobe within the lateral fissure.
- **Core** region: includes primary cortex
- **Belt** surrounds the core region (secondary cortex)
- Secondary cortex outside the belt referred to as **parabelt** areas
- ~10 separate areas of secondary auditory cortex in primates
- Primary auditory cortex organized in functional columns with neurons responding optimally to sounds in same frequency range.
- Also organized tonotopically with each area of primary & secondary auditory cortex being organized on the basis of frequency



General location of the primary auditory cortex and areas of secondary cortex

What Sounds Should Be Used to Study Auditory Cortex?

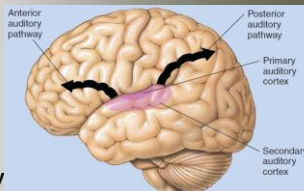
- Several reasons why research on the auditory system has fallen behind:
- Lack of understanding of the dimensions along which auditory cortex evaluates sound
- Although we know there is a hierarchical organization, the cells that respond to complex sounds are not understood
- Difficult to know how to probe the system with the right acoustic stimuli.

Two Streams of Auditory Cortex

- Auditory signals are conducted to two areas of association cortex:

- Prefrontal cortex
- Posterior parietal cortex

- Anterior auditory pathway may be more involved in identifying sounds (what)
- Posterior auditory pathway may be more involved in locating sounds (where)



The hypothesized anterior and posterior pathways

Auditory-Visual Interactions



- There is evidence for interactions between the auditory and visual systems
 - e.g. some posterior parietal neurons have visual and auditory receptive fields
- Interaction in primary sensory cortices indicate that sensory system interaction is an early and integral part of sensory processing
- So, not just something that happens after the system has completed its analysis.

Where Does the Perception of Pitch Occur?



- Most auditory neurons respond to changes in frequency rather than pitch
- One small area just anterior to primary auditory cortex has neurons that respond to pitch rather than frequency
 - This may be where frequencies of sound are converted to perception of pitch

Effects of Damage to the Auditory System



- Lesions of auditory cortex in rats results in few permanent hearing deficits, suggesting the subcortical circuits may be more complicated than once thought.
 - Lesions in monkeys and humans hinder sound localization and pitch discrimination
- Deafness in humans**
- Total deafness is rare, due to diffuse multiple pathways existing and continue to carry flow of information.
 - Two kinds: conductive deafness (damage to ossicles) and nerve deafness (damage to cochlea)
 - Partial cochlear damage results in loss of hearing at particular frequencies

Somatosensory System: Touch and Pain



Somatosensory system is three separate and interacting systems:

- Exteroceptive – senses external stimuli
- Proprioceptive – monitors info on body position
- Interoceptive – provides info on body conditions (e.g., temperature and blood pressure)

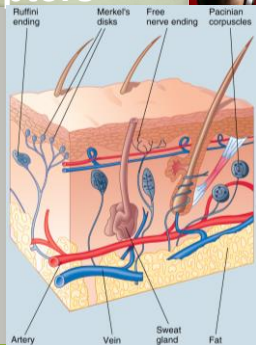


Cutaneous Receptors



Cutaneous = relating to or affecting the skin...

1. **Free nerve endings:** Sensitive to temperature and pain
2. **Pacianian corpuscles:** Adapt rapidly, large and deep; onion-like & respond to displacement of skin
3. **Merkel's disks:** adapt slowly to gradual skin indentation
4. **Ruffini endings:** adapt slowly to gradual skin stretch



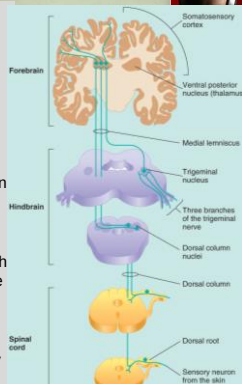
Four cutaneous receptors that occur in human skin

Two Major Somatosensory Pathways



1. Dorsal-column medial-lemniscus system

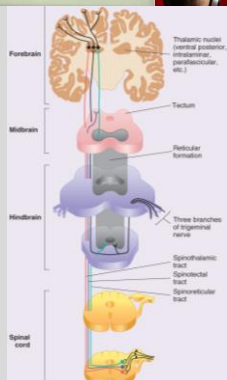
- Carries info on touch & proprioception
- Sensory neurons enter spinal cord via dorsal root & ascend ipsilaterally in dorsal columns and synapse in dorsal column nuclei of the medulla.
- Axons of dorsal column nuclei neurons cross over to other side of brain & ascend in to medial lemniscus to contralateral ventral posterior nucleus of the thalamus.
- Ventral posterior nuclei also receive input via 3 branches of the trigeminal nerve which carries somatosensory information from the contralateral areas of the face.
- Most neurons of ventral posterior nucleus project to primary somatosensory cortex, others project to secondary somatosensory cortex.



Two Major Somatosensory Pathways

2. Anterolateral system

- Most dorsal root neurons synapse as soon as they enter the spinal cord.
- Axons of most second order neurons cross over to other side but then ascend to the brain in the contralateral anterolateral portion of the spinal cord, however some also ascend ipsilaterally.
- The anterolateral system comprises 3 tracts: 1. Spinothalamic tract (projects to ventral posterior nucleus of thalamus); 2. Spinoreticular tract (projects to reticular formation) 3. Spinotectal tract (projects to the tectum).
- If both paths are damaged by spinal injury then the person will not be able to feel any body sensations below the level of the cut.



Cortical Areas of Somatosensation

- Primary somatosensory cortex (SI):
 - Includes the Postcentral gyrus
 - Has Somatotopic organization (somatosensory homunculus) – more sensitive, more cortex
 - Input largely contralateral
- Secondary somatosensory cortex mainly receives input from the primary somatosensory cortex
- Somatotopic; input from both sides of the body
- Much of the output from SI and SII goes to association cortex in posterior parietal lobe

Somatosensory System & Association Cortex

- **Somatosensory signals are conducted to the highest level of the sensory hierarchy:**
 - to areas of association cortex in the prefrontal and posterior parietal cortex.
- **The posterior parietal cortex contains bimodal neurons**
 - Neurons that respond to activation of two different sensory systems
 - In this case both somatosensory and visual stimuli.

Somatosensory Agnosias

1. **Astereognosia** – inability to recognize objects by touch
 - pure cases are rare – other sensory deficits are usually present
2. **Asomatognosia** – the failure to recognize parts of one's own body
 - Usually associated with damage to right posterior parietal lobe which affects left side of the body.

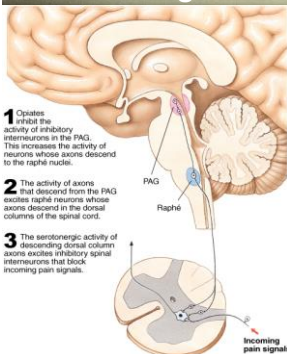


Perception of Pain

- Despite its unpleasantness, **pain is adaptive** & needed
- **No obvious cortical representation of pain**
- Painful stimuli can elicit pain in primary & secondary somatosensory cortex but removal of these areas is not associated with changes in threshold for pain.
- (although anterior cingulate gyrus appears involved in the emotional component of pain)
- **Descending pain control** – pain can be suppressed by cognitive and emotional factors



Descending Pain Control



Circuitry identified by the following studies:

- Electrical stimulation of the periaqueductal gray (PAG) has analgesic effects
- PAG and other brain areas have receptors for opiate analgesic drugs (e.g., morphine)
- Existence of endogenous opiates (natural analgesics) – endorphins could be isolated



Basbaum and Fields's (1978) model of the descending analgesia circuit

Neuropathic Pain



- Severe chronic pain in the absence of a recognizable pain stimulus
- Exact mechanism is unknown but likely from pathology of nervous system linked to an injury
- Some evidence for aberrant (diverging from normal function) glial cell signals triggering neural pain pathways



Selective Attention

Has 2 characteristics:

- Improves perception of what is attended to with that which is not
- Internal cognitive processes (endogenous attention) and external events (exogenous attention) focus attention.
- There is a consensus that the prefrontal cortex and the posterior parietal cortex play a major role in directing top-down attention

Cocktail-party phenomenon:
Indicates that there is processing of information not attended to.



Neural Mechanisms of Attention

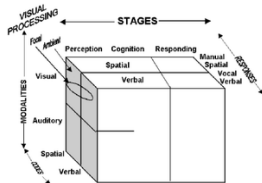
- Selective attention is thought to work by strengthening neural responses to attended-to aspects and weakening responses to others
 - E.g., spatial attention can shift the location of receptive fields (Wommelsdorf et al. 2006)
- Recording from neurons in a monkey's secondary visual cortex in the dorsal stream revealed receptive fields of many neurons shifted toward points in the visual field to which the monkey was attending.
 - This shows a degree of neural plasticity in the attentional system.



Multiple Resources (Wickens, 1984)



- There are independent processing mechanisms in the form of multiple resources.
- 3D structure of processing with four stages
- Helps explain why similarity of task is critical.
 - i.e., 2 tasks that are similar will compete for the same resources and cause more interference.



More interference when two tasks share same modality:
e.g., two auditory messages
harder to follow than one
auditory and one visual
(Treisman & Davies, 1973).

Simultanagnosia



Simultanagnosia – a difficulty attending to more than one visual object at a time.

Typical cause: bilateral damage to dorsal stream of posterior parietal cortex, which is responsible for visually localizing objects in space.