Vision & Hearing: From Molecules to Sensory Loss

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Outline

● Brief Overview of Neurotransmission
● The Senses and the Brain
  ○ Vision
  ○ Hearing
● Sensory Loss and the Brain
  ○ Vision Loss
  ○ Hearing Loss
Neurons communicate via synapses

- Synapses: junctions between two neurons
- Neurotransmitters: chemical messengers released from neurons at synapses so they can communicate with neighboring cells
Release of neurotransmitters can cause depolarization or hyperpolarization

- Some neurotransmitters are viewed as “excitatory”
  - Target neurons are more likely to fire an action potential
- Some neurotransmitters are viewed as “inhibitory”
  - Target neurons are less likely to fire an action potential
Brief review of action potentials

- When a neuron is not sending signals, it is at rest.
- An action potential occurs when a neuron sends information down an axon, away from the cell body.
- If the signal is strong enough, it will trigger the action potential.
- The neuron becomes hyperpolarized.
The Senses: Interacting with the World

- Vision
- Audition
- Somatosensation
- Olfaction
- Gustation
- Balance
- Nociception
- Proprioception
- Thermoception
Sensation and Perception

Input → Transduction → Processing → Perception

- Sensation: Input of stimuli from the environment.
- Perception: Interpretation and understanding of the environment.
- Transduction: Conversion of physical energy into neural signals.
- Processing: Further analysis and interpretation of neural signals by the brain.
Vision
Visual Input: Light

Spectrum

Intensity
Visual Sensory Transduction: The Eye
Visual Sensory Transduction: The Eye

- Photoreceptors
  - Rods
  - Cones
- Bipolar cells
- Ganglion cells
Humans have two types of photoreceptors

<table>
<thead>
<tr>
<th>Rods</th>
<th>Cones</th>
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<tr>
<td>High sensitivity</td>
<td>Low sensitivity</td>
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<tr>
<td>Single wavelength</td>
<td>Multiple wavelengths (color)</td>
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<tr>
<td>Peripheral retina</td>
<td>Central retina</td>
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<tr>
<td>Dim light vision</td>
<td>Bright light vision</td>
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Fig. 20. Graph to show rod and cone densities along the horizontal meridian.
Photoreceptors are highly compartmentalized

- Phototransduction occurs in the outer segment
- Mitochondria and ER are for energy production
- Neurotransmitters are released from terminal
Major players in phototransduction

Opsin: light-sensitive receptor

cGMP: second messenger that keeps photoreceptors in depolarized state
Phototransduction involves 3 major steps

1. Light enters the eye and activates the opsin molecules inside the photoreceptors
2. Activated rhodopsin causes a reduction in cGMP
3. Photoreceptor is hyperpolarized following light exposure
Inactivation of phototransduction
Visual Sensory Transduction: The Eye

- Retina
- Fovea
- Optic Nerve
- Scotoma
- Visual Field

Diagram showing the eye with labels for parts such as Retina, Fovea, Optic Nerve, Scotoma, and Visual Field.
Visual Processing

<table>
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<tr>
<th>Orientation</th>
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<th>Contrast</th>
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</table>
Visual Processing

Motion
Visual Processing: Visual Neurons

- Receptive Field
  - Orientation
  - Color
  - Motion
Visual Processing: The Visual Pathway
Visual Processing: Visual System Organization

Retinotopic Map

Orientation Columns

Cortical Magnification

Ocular Dominance Columns
Visual Processing: Visual System Organization

- Hierarchical Organization
Visual Processing: Visual System Organization

- Specialized Areas

- Wernicke’s area
- Broca’s area
- Superior temporal sulcus
- Parahippocampal place area
- Amygdala
- Orbitofrontal region
- Prefrontal cortex
- Medial region
- Auditory cortex
- Primary visual cortex
- Fusiform face area
Visual Processing: Visual Pathways

Dorsal Stream

- "where" pathway
- orientation
- direction
- depth

Ventral Stream

- "what" pathway
- color
- shape
- Recognized
  Object ready for perception
Visual Perception

- Gestalt psychology
- Visual illusions
  - Moving dot motion
  - Barber pole illusion

It doesn't matter in what order the letters in a word are, the only important thing is that the first and last letter be at the right place. The rest can be a total mess and you can still read it without problem. This is because the human mind does not read every letter by itself, but the word as a whole.
Hearing
Auditory Input: Sound

- Spectrogram
- Waveform
Auditory Sensory Transduction: The Ear

- Pinna & ear canal
- Ear drum
- Ossicles
  - Malleus
  - Incus
  - Stapes
Auditory Sensory Transduction: The Cochlea

- Basilar membrane
- Hair cells with stereocilia
Auditory Sensory Transduction: The Cochlea

- Basilar membrane
- Hair cells with stereocilia
Mechanotransduction by Hair Cells

- Sound
- Basilar membrane upward
- Reticular lamina upward
- Stereocilia bend outward
- Mechanically gated K+ channels open
- Hair cell depolarizes
- Calcium-mediated Glutamate release

(b)

(a)

Mechanically gated channel

K+

Stereocilia

Depolarization

Tip link

Voltage-gated calcium channel

Ca2+

Endolymph

Reticular lamina

Inner hair cell

Vesicle filled with excitatory neurotransmitter

Spiral ganglion neurite

Penilymph
Auditory Processing: Auditory Neurons

- Receptive Field
  - Frequency
  - Intensity
  - Timing
Auditory Processing: The Auditory Pathway
Auditory Processing: Auditory System Organization

Tonotopic

Head Shadow

Monaural vs. Binaural Segregation
Auditory Perception

- Pitch
- Timbre
- Loudness
Auditory Perception

https://www.youtube.com/watch?v=dP15zlyra3c
Auditory Perception

Jumbled Speech

Shepard Tone

Music
<table>
<thead>
<tr>
<th></th>
<th>Vision</th>
<th>Hearing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Who</strong></td>
<td>Facial recognition</td>
<td>Speech comprehension</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sound discrimination</td>
</tr>
<tr>
<td><strong>What</strong></td>
<td>Object recognition</td>
<td>Object recognition</td>
</tr>
<tr>
<td></td>
<td>Retinotopic map</td>
<td>Tonotopic map</td>
</tr>
<tr>
<td><strong>Where</strong></td>
<td><strong>Spatial location</strong></td>
<td>Spatial location</td>
</tr>
<tr>
<td></td>
<td>Retinotopic map</td>
<td>Interaural timing/intensity differences</td>
</tr>
<tr>
<td><strong>When</strong></td>
<td>Temporal resolution</td>
<td>Temporal resolution</td>
</tr>
</tbody>
</table>
Sensory Systems and Beyond
When Inputs Decline
Vision Loss: Peripheral Mechanisms

Myopia

Hyperopia

Normal Vision
Vision Loss: Peripheral Mechanisms

- Cataracts
- Glaucoma
- Macular Degeneration
Vision Loss: Central Consequences

- Crossmodal changes following blindness (recruitment of occipital visual cortex)
  - Braille reading and tactile discrimination
  - Auditory localization and discrimination
  - Verbal memory and language

- Crossmodal changes following deafness (recruitment of auditory cortex)
  - Sign language
  - Visual tasks
  - Vibro-tactile stimulation
Vision Loss: Treatments

Cataract Removal

Corrective Lenses

Lasik Surgery

Drug and Regeneration Therapeutics
Sarah’s Research: Blast-Induced Vision Loss

- Between 2000-2010, almost 200,000 eye injuries occurred in military populations following blast exposure
- Up to 40% of monocular blindness is due to ocular trauma
- Our lab models blast-induced vision loss
Tree shrews to study ocular blast injury

- Tree shrews have eyes that are very similar to humans!
- Repeat blast injury → regeneration of injury ganglion cells
Types of Hearing Loss

Conductive Hearing Loss

Sensorineural Hearing Loss

Incus
Malleus
Hearing Loss: Peripheral Mechanisms

Conductive Hearing Loss

○ Cerumen impaction
○ Eardrum perforation
○ Ear infection
○ Cholesteatoma
○ Otosclerosis
Hearing Loss: Peripheral Mechanisms

Sensorineural Hearing Loss

○ Noise exposure
○ Aging
Jane’s Research: Noise-Induced Hearing Loss

• High prevalence, especially among veterans
  ○ 1 in 6 U.S. adults have hearing loss
  ○ Tinnitus and hearing loss are #1 and #2 disabilities seen in the VA

• Most common complaint: difficulty hearing in noisy environments

• Sensorineural hearing loss
  ○ Preceded by inner hair cell synapse loss (synaptopathy or “hidden hearing loss”)
Behavioral Hearing Tests

Nonhuman Primate Model

Clinical Objective Testing (Electrophysiology)

Invasive Brain Recordings

Anatomy of the Cochlea and the Brain
Hearing Loss: Central Consequences

Tonotopic Reorganization
Hearing Loss: Central Consequences

Crossmodal Reorganization
Hearing Loss: Treatments

Cerumen Removal

P.E. Tubes

A small incision is made in the tympanic membrane
Tube inserted to drain fluid

Surgery

Damaged malleus
Damaged incus
Eardrum
Healthy stapes
Prosthesis
Stapes
Hearing Loss: Treatments

Hearing Aids

Remote Microphones
Hearing Loss: Treatments

Cochlear Implants
Hearing Loss: Treatments

Drug and Regeneration Therapeutics

Aural Rehabilitation
Take Home Message

● Hearing and vision are special senses that allow us to communicate and perceive our environment

● Damage to the eyes or ears leads to changes in the brain

● Treatments for vision and hearing loss are on the horizon
Questions?

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