COGS 107B – Systems Neuroscience

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Fri 11:00 11:50 CSB 005
OH: Fri 9:00–10:50 CSB 232

1/26/16
I love taking mid-term exams...
Said no one ever.
Today’s Schedule

1. Lecture 4: Vestibular System.
2. Lecture 5: Visual System
3. Lecture 6: Auditory System
The Vestibular System

1) Postural reflexes.
2) Gaze adjustment.
3) Assessment of self-motion
4) A reason not too drink too heavily
Semicircular Canals and Otolith Organs

Vestibular 2 min Neuro
Both Contain Hair Receptors
Hair Cell

- Deflection towards kinocilium = excitation.
- Deflection away from kinocilium = inhibition.
Hair Cell

- Transduces head direction/motion and sound waves into neural signals.
Semicircular Canal

**Transient** information about changes in head orientation (rotational velocity).
Endolymph causes movement of cupula

Cupula

Endolymph in semicircular canal

Hair cell

Crista ampullaris

Movement of semicircular canal with body movement

Head Movement

Cupula

Christa Ampullaris

left side: inhibition

right side: excitation

Movement of semicircular canal with body movement
Otolith Organs: Sustained encoding of Linear Motion and head orientation relative to gravity
Two Types of Otolith Organs: Utricle and Saccule

**Utricle:** Hair cells oriented vertically. Gives **horizontal head orientation information.**

**Saccule:** Hair cells oriented horizontally. Gives **vertical information.**
Head Rotation Leads to Eye Movement

Compensating eye movement

- Excitation of extraocular muscles on one side.
- Inhibition of extraocular muscles on the other side.

Lateral rectus
Medial rectus

Oculomotor nucleus (midbrain)
Abducens nucleus (pons)
Vestibular nucleus (pons)

Saccule, utricle, and semicircular canals

Detection of rotation

Head rotation

Right
Left

Inhibition
Excitation
Head Direction Cells

• Head relative to the world (not the body). How the head is oriented in the room.
• Dorsal Tegmental Nucleus: Integration of info from Otolith and Semicircle.

Clockwise Movement (amount or speed)
Vestibular System

- Semi-circular canals (3)
  - Transient
  - Rotation of head/Angular movement

- Otolith organs (2)
  - Utricule
  - Saccule
  - Sustained
  - Linear movement/gravity
Lecture 5: Vision

Principle of the week:

**Overlay of Egocentric Maps:** Visual information is encoded within an egocentric coordinate system in multiple forms that map onto each other nicely.
Anatomy of the Eye

**Retina:** Layer of tissue containing photoreceptors and ganglion cells.

**Fovea:** Small depression in the retina where the cones type of photoreceptors are particularly concentrated.

Photoreceptors ➔ Ganglion Cells ➔ Brain
Photoreceptors
Hyperpolarized by Light (less Glu Release)

Rods
- One type.
- Positioned along periphery
- Very sensitive to light.
- They are sensitive to color, too.

Cones
- Three types:
  - S (437nm)
  - M (533nm)
  - L (564nm)
- Concentrated on fovea.

<table>
<thead>
<tr>
<th>Animal</th>
<th>Fovea</th>
<th>Periphery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human</td>
<td>90</td>
<td>1</td>
</tr>
<tr>
<td>Non-human primate</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>Rat</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>
Ganglion Cells Response Fields

Great for Edge Detection!
Retinal Ganglion Cells

- First time you see Action Potentials take place.
- 3 types: Parvocellular-X (On/Off)  
  Magnocellular -Y(On/Off)  
  Koniocellular

(SUSTAINED RESPONSE)  
(TRANSIENT RESPONSE)
# Ganglion Cells

<table>
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<th>Parvocellular-(X)</th>
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<td><strong>Percent of ganglion cell population</strong></td>
<td>~80%</td>
<td>~10%</td>
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Visual Pathway

Right Visual Field → Left Retina → Left LGN → Left V1

Left Visual Field → Right Retina → Right LGN → Right V1
The LGN of the Thalamus

Magnocellular: Layers 1 & 2
Parvocellular: Layers 3, 4, 5, & 6
Koniocellular: In-between (Color)

Each layer carries info from one eye. They alternate.

Ex: Left LGN, Right Visual Field, Info from both eyes.

1 – Left eye
2 – Right eye
3 – Left eye
4 – Right eye
5 – Left eye
6 – Right eye

RETINOTOPIC MAP! (triangle)
Primary Visual Cortex (Striate Cortex area V1)

Golgi Stain: Entire neuron.
Nissl Stain: Cell body.
Weigert Stain: Axons.
V1: Overlay of Egocentric Maps

Principle of the week:

**Overlay of Egocentric Maps:** Visual information is encoded within an egocentric coordinate system in multiple forms that map onto each other nicely.

Four maps:
1) Retinotopic
2) Ocular Dominance
3) Orientation Tuning
4) Color
1. Retinotopic Map

Left Visual Field $\rightarrow$ Right Hemisphere

Right Visual Field $\rightarrow$ Left Hemisphere

- Image flips/inverted (Look at smiley face)
- Fovea is always more anterior
2. Ocular Dominance Columns

Cytochrome oxidase: Huebel and Wiesel. Enzyme that synthesizes ATP (energy needed for the neuron to fire action potentials).

Pirate kitty only uses left eye
3. Orientation Tuning

- Neurons in V1 sensitive to bars of light.
- This neuron prefers vertical bars.

One column; sensitive to same spot VF and same orientation

Multiple columns; continuum of orientations.
3. Orientation Tuning (Pinwheels)

- In V1, neurons responding to the same orientation are grouped (colors).
- The groups are organized around a central point forming a pinwheel (arrows).

NOTE: This slide is not about color, it is about orientation. The author used different colors to code populations of neurons sensitive to a particular orientation of a bar of light.
4. Color

- LGN koniocellular layers project to striate cortex layers II,III in a ‘blob’-like fashion.

- Blobs carry color info.

- **Blob centers follow the contours of ocular dominance columns.**
Putting All the Maps Together

1. Retinal space

2. "Blob" (koniocellular - color info)
   "Pinwheel" (colors = orientation pref.)

3. L-eye
4. R-eye
Putting All the Maps Together

V1 neurons:
1) sensitive to a particular spot of the visual field. (retinotopic map)
2) sensitive to left or right eye, one field of vision (ocular dominance)
3) sensitive to a particular orientation of a bar of light (orientation tuning)
4) sensitive to a particular color (koniocellular)
Visual Pathways

What?
- Ventral pathway
- Visual Cortex → Inferotemporal Cortex (IT).
- Object identification

Where?
- Dorsal pathway
- Visual Cortex → Posterior Parietal Cortex (PPC).
- Detection of movement direction.
Neurons fire to edges where figure meets background.
Lecture 6: The Auditory System

Principle of the week:

**Active Sensing**: Perception is an active process. We are equipped to decode certain types of information.
A speaker will compress air as the diaphragm moves out. When the diaphragm retracts, it leaves lower (rarefied) pressure areas. This pressure oscillation will travel as a sound wave to your ear.
# Sound Waves

<table>
<thead>
<tr>
<th>Physical Dimension</th>
<th>Definition</th>
<th>Perceptual Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Amplitude</strong></td>
<td>Difference in pressure between high and low peaks of the wave.</td>
<td><strong>Loudness (dB)</strong></td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
<td>Number of cycles given a time period.</td>
<td><strong>Pitch (Hz)</strong></td>
</tr>
<tr>
<td><strong>Complexity</strong></td>
<td>Additive waveform.</td>
<td><strong>Timbre</strong></td>
</tr>
</tbody>
</table>
The Fourier Transform decomposes a signal into the frequencies that make it up. So does the basilar membrane!!!
The Auditory Pathway

Pinna → External → Tympanic → Ossicles → Oval Window → Cochlea

Auditory Canal (Malleus) → Membrane (Eardrum) → (Incus) → Stapes
middle ear muscle contractions amplify sound in a frequency-dependent fashion (acts as an equalizer).
**The Cochlea – Basilar Membrane**

- **Base of Basilar Membrane**: Narrow and stiff
- **Apex of Basilar Membrane**: Wide and floppy
- **High frequency tones**
  - (a) High frequency
  - (b) Low frequency
  - (c) Frequency producing maximum amplitude
The Cochlea – Basilar Membrane

Basilar membrane decodes: component frequencies & amplitudes

Neuroscience: Exploring the Brain, 3rd Ed. Bruce, Center; and Paradiso Copyright © 2007 Lippincott Williams & Wilkins
Tonotopy in Cochlear Nucleus

- As you leave the cochlea, the spiral ganglion cells start to fire action potentials.
- Axons of ganglion cells form the auditory nerve, which goes to the cochlear nucleus (brainstem).
- A single spiral ganglion cell is receiving info from one hair cell.
- That segregation from basilar membrane to spiral ganglion cells is preserved as you enter the cochlear nucleus.

Segregation = Topographic Representation
Tonotopy in A1

- The tonotopic map ultimately reaches the primary auditory cortex (A1 in Heschl’s gyrus).
ascending pathways of the mammalian auditory system

Stapes → Oval Window → Cochlea → Auditory → Cochlear → Medulla → Inferior → Thalamus → Auditory
(S)  (OW)  (C)  Nerve  Nucleus  (LSO/MSO)  Colliculus  (MGN)  Cortex
(AN)  (CN)  (MNTB)  (IC)  (AC)
How a neuron will respond to different frequency tones at different volumes

• Present a tone of a particular frequency and record from the neuron to see if it fires.
• If it doesn’t fire at a low volume, you turn up the volume one notch and present it again.
• When it fires, you put a black dot in the graph

Characteristic Frequency (CF): Frequency at which a given neuron responds to the smallest sound intensity (lowest volume).

All tone frequencies will be represented in the cochlear nucleus.
Green: What causes the cell to fire. (Ex: Type I fires a 5kHz at low volume),
Gray: Baseline firing of the cell (when no sound is coming in)
Pink: Inhibitory region

Response Fields in Cochlear Nucleus Neurons
Auditory nerve synapses into cells of the cochlear nucleus that have different morphologies (shapes).

- **Cochlear Ganglion Cell**: Sustained response.
- **Globular Bushy Cell**: Sustained response to preferred frequencies.
- **Octopus Cell**: Transient response to preferred frequencies.
the ‘where’ of sound – sound source localization by comparison of inputs to the left and right ears

Interaural Time Difference (ITD)

Interaural Level Difference (ILD)

Azimuth: Left to right.

not useful for persistent high frequency sounds (>2000 Hz) as hair cell responses do not oscillate in response to high frequency tones

not useful for low frequency sounds as their amplitude is less impacted by the head
Medial Superior Olive (MSO): Detects interaural time differences. (ITD)

- MSO receives info from both cochlear nuclei.
- When they reach MSO neuron simultaneously, it will cause it to fire.
- Axon from contralateral side is longer, so it takes more time for info to travel.
- MSO cells are sensitive to information coming at different delays.
Lateral Superior Olive (LSO): Detects interaural level differences (ILD).

- Ipsilateral Cochlear Nucleus: Sends an excitatory projection.
- Contralateral Cochlear Nucleus: Sends an excitatory projection BUT first stops at MNTB (Medial Nucleus of Trapezoid Body).
- MNTB neurons are inhibitory (in red) and project to the LSO.
- Ultimately rendering the projection from the contralateral side inhibitory.

Main Point: Inhibition of cell when sound is in the contralateral side.
timing matters: A1 responses to pure tones are modulated by the frequency ordering of preceding tones

A1 preferred frequency map (tonotopy)

preferred frequency = pitch for which amplitude necessary to give a response is lowest

A1 preferred ‘sweep direction’ map

preferred direction = ordering (low→high vs. high→low) of frequencies in a frequency sweep that produces the strongest response to the preferred frequency
• bats use shorter ‘FM’ sweeps to assess their proximity to their prey.
• prey size can be determined by the echo amplitude (closer = louder)
• bats use long ‘CF’ calls to assess Doppler shift and, in turn, the movement speed of their prey.
# Touch Receptors in Skin

<table>
<thead>
<tr>
<th>Type</th>
<th>Looks like</th>
<th>RA/ SA</th>
<th>Depth</th>
<th>Response field</th>
<th>Sensitivity</th>
<th>Best stimulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacinian Corpuscle</td>
<td>(Onion)</td>
<td>RA</td>
<td>Deep</td>
<td>Very Large/Hand</td>
<td>Very high</td>
<td>High frequency vibration.</td>
</tr>
<tr>
<td>Meissner Corpuscle</td>
<td>(Pancakes)</td>
<td>RA</td>
<td>Shallow</td>
<td>3-5 mm</td>
<td>Micro-slips.</td>
<td>Low frequency vibration</td>
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<tr>
<td>Merkel Disk</td>
<td>(Flowers)</td>
<td>SA</td>
<td>Shallow</td>
<td>Spotty 2 - 3mm</td>
<td>Broad depth range.</td>
<td>Form, texture. Points, edges.</td>
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Propioceptors: Summary

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<tr>
<th>Muscle Spindle Afferent</th>
<th>Golgi Tendon</th>
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<tr>
<td>Muscle stretching.</td>
<td>Muscle contracting.</td>
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<tr>
<td>Transient response (fast adapting)</td>
<td>Sustained response (slow adapting)</td>
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![Muscle Spindle Afferent Diagram]

![Golgi Tendon Diagram]
Vestibular System

- Semi-circular canals (3)
- Otolith organs (2) Utricule Saccule

- Transient
- Sustained

- Rotation of head/Angular movement
- Linear movement/gravity
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http://dnitz.com/#teaching
Resource Questions

1) The action potential and synaptic potential are actually special cases of the membrane potential.

True
Resource Questions

2) Name 3 properties of ion channels: __________

_________ __________

Ion selectivity
Gating
Kinetics
State
Distribution
3) The neurotransmitter GABA:
A. is inhibitory
B. B. opens Cl- channels
C. is excitatory
D. Is a neuromodulator
E. depolarizes post-synaptic targets
F. A and B
G. C and E
Resource Questions

4) The 'Pinocchio Effect' involves a resolution of contradictory information supplied by which two sensory systems of the brain?

Somatosensory system and Proprioceptive system.
5) (circle the appropriate word) Generator potentials are analogous to [synaptic] / [action] potentials.
6) 'Microslip' events are best detected by the ______ of touch receptor

Meissner corpuscle
7) (circle the appropriate word) Recordings of neurons along [oblique] / [vertical] trajectories through visual cortex yield neurons with different directional tuning preferences.
8) Which type of bipolar neuron is depolarized by the neurotransmitter glutamate?

Off-Bipolar
9) Ganglion cells of which type have responses to light that are analogous to Pacinian corpuscle responses to touch?

Magnocellular (transient response)
10) On an otherwise dark field of view, light in the form of a plus sign in the upper-left field of view will excite neurons in the:

A. right-upper V1
B. right-lower V1
C. left-upper V1
D. left-lower V1
• Inter-aural level differences are registered by neurons of the:

A. lateral superior olivary nucleus
B. primary auditory cortex
C. medial geniculate body
D. medial superior olivary nucleus
Resource Questions

• True / False - The responses of cochlear nucleus neurons to pure tones are homogenous and like those of cochlear ganglion cells
Resource Questions

• Low-frequency tones produce the most oscillation at this part of the basilar membrane which is:
  A. base, narrow and floppy
  B. base, wide and floppy
  C. apex, narrow and stiff
  D. apex, wide and floppy
Neuron A responds to an isolated 10 KHz tone by firing 3 action potentials per second. However, if preceded by a 5 KHz tone, the same neuron's response to the 10 KHz tone is to fire 20 action potentials per second. This is a good example of Population Coding.
Resource Questions

• Circle the appropriate answer - The bat uses [FM delay] / [CF delay] to determine target distance, but uses [interaural time differences] / [CF pitch shifts] to determine target velocity.