COGS 107B
Systems Neuroscience

B03
Fri 5-5:50p WLH 2113

Nhi Nguyen
nny024@ucsd.edu
OH: Fri 6-6:50p WLH 2113
Week 3 - Lectures

1. the visual system (vision I $\rightarrow$ retina $\rightarrow$ striate cortex)
   a. Principles: ‘overlay of egocentric maps I’
      & ‘overlay of egocentric maps II’

2. the auditory system and echolocation
   a. Principle: ‘active sensing’
Retinal ganglion cells (output cells of retina)

**Principle:**

*Overlay of egocentric maps* = information laid on top of each other (on their own - give little information, together - provide info about world)

V1, V2, V4 → **PPC (parietal lobe)** - “where” & **IT (temporal)** - “what”
Photoreceptors → bipolar cells → ganglion cells → brain

- **Photoreceptors:**
  - Rods (sensitive to light - along periphery)
  - Cones (colors - 3 types - concentrated in fovea)

- **Bipolar cells:**
  - can be excited or inhibited by photoreceptors and interneurons (amacrine and horizontal cells) modify ganglion cell response to bipolar cells

- **Ganglion cells:**
  - Parvocellular-X (on/off): ~80%, small r.f, high resolution, sustained/persistent response
  - Magnocellular-Y (on/off): ~10%, large r.f., low resolution, transient response (change)
  - Koniocellular (color): 10%

Visual world is broken down into lines (ganglion cells response fields - response fields (detect edges))
Photoreceptors

**Light** $\Rightarrow$ photoreceptors hyperpolarize (isomerized) (decrease GLU release)

**Darkness** $\Rightarrow$ GLU released $\Rightarrow$ graded depolarizations
Bipolar Cells: mechanisms for ‘on’ and ‘off’ responses

'ON' bipolar

0 mV
-40 mV

light on

'OFF' bipolar

0 mV
-40 mV

light on
Bipolar Cells: mechanisms for ‘on’ and ‘off’ responses
Ganglion Cells

X-'on', X-'off', Y-'on', and Y-'off' ganglion cells

firing rate - Hz
(action potentials / second)

light on

light on
## Ganglion Cell: output of the retina

<table>
<thead>
<tr>
<th>Property</th>
<th>Parvocellular-(X)</th>
<th>Magnocellular-(Y)</th>
<th>Koniocellular</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surround inhibition</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>(luminance opponency)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color opponency</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Receptive field size / resolution</td>
<td>Small / high</td>
<td>Large / low</td>
<td>?</td>
</tr>
<tr>
<td>Response to light</td>
<td>Sustained</td>
<td>Transient</td>
<td>?</td>
</tr>
<tr>
<td>Low-contrast, moving stimuli</td>
<td>Weak response</td>
<td>Strong response</td>
<td>?</td>
</tr>
<tr>
<td>Percent of ganglion cell population</td>
<td>~80%</td>
<td>~10%</td>
<td>~10%</td>
</tr>
</tbody>
</table>
4 Egocentric maps that are overlaid onto a **spatial register in V1** (retinotopic space):

1. Retinotopic Map (position on the retina)
2. Ocular Dominance Columns
3. Directional/Orientation tuning (pinwheel)
4. Lay out of Koniocellular input into V1
1. **Retinotopic Map (position on the retina)**

1. Neurons in retina responding to light adjacently in the visual field, sit next to each other in retina
2. project to places next to each other in LGN - stimulation of adjacent parts on retina, will yield activation of adjacent neurons in LGN → project to V1 adjacently, too.
3. The LGN (6 layers): 1 & 2 = **magnocellular layer**; 3-6 = **parvocellular layers**
4. Flip vertical → flip horizontal
5. 4 → 2&3 → 5&6 → output to other places
6. All 3 ganglion cells meet in layer 2 & 3
   c. Weigert Stain: Axons.
overlay of egocentric maps in V1 - the first map – retinotopic

THE MAPPING OF THE FIELD OF VIEW ONTO THE RETINA IS AN EXAMPLE OF A TOPOGRAPHIC REPRESENTATION: the left visual field light is represented (excites V1 neurons) in the right striato/V1 cortex (and vice versa) – the upper half of the visual field is represented in the bottom half of V1 (and vice versa) – light hitting the retina close to the fovea excites neurons in the central lateral region of V1 (light hitting the outer edge of the retina excites neurons in the central medial region of V1)
2. Ocular Dominance Columns

1. Lateral Geniculate Nucleus (LGN) projections to the visual cortex form ocular dominance columns corresponding to inputs from the left and right eye – visualized via cytochrome oxidase staining – dominance map is aligned to retinotopic map. *(which eye did it come from?)*

2. Depth - more things are different, the further away they are

3. **Orientation tuning in V1** - **BARS** of light, not pinpoints
3. Directional/Orientation tuning (pinwheel)

1. V1 neurons respond preferentially to bar stimuli having certain orientations
2. across V1, neurons responding to the same orientation are grouped
3. groups of like-responding neurons are, in turn, organized in a repeating fashion around a central point forming ‘pinwheels’
4. pinwheel centers follow the contours of ocular dominance columns (are along the lines of the ocular dominance columns)
5. Center of ODC is where all the different orientations meet
4. Lay out of Koniocellular input into V1

- LGN koniocellular layers project to **striate cortex layers II,III** in a ‘blob’-like fashion
- ‘blob’ neurons are **color-sensitive**
- ‘blob’ centers follow the contours of ocular dominance columns
V4 and V2 = Figure/ground distinction

figure/ground distinctions already emerge in area V2, but dependence on retinotopic location remains

- a V2 neuron firing when the edge is the right side of an object and in a specific retinotopic position
- switches in edge ownership can drive excitation versus inhibition for the same stimulus at a given retinal position
- sensitivity to object space is also found for objects in natural scenes
along the ‘where’ pathway: area MST integrates optic and vestibular ‘flow’
area VIP of parietal cortex: bringing together personal spaces of the somatosensory and visual systems
6. the auditory system I

- Sound = compression vs rarefied (release) air of particle concentration in space
- **Fourier analysis/transform** decomposes complex sound into the different pure tones or frequencies that make up the complex sound (break down sound into frequency vs power (amplitude)). Varying stiffness of the basilar membrane results in a Fourier transform of the vibrations of the endolymph.
Ear anatomy

**Outer ear:**
- **Pinna:** for sound localization of height (shape reflects sound from different sources in different ways)
  - delay
- **Ear canal:** protects eardrum at the end of the canal, amplifies frequencies b/w 2000-5000 Hz
- **Tympanic membrane** (eardrum)

**Middle ear:**
- **Ossicles** (hammer => anvil => stirrup): vibration **amplifier** (vibratory articulation)
- middle ear bones amplify sound by changing the way the bones move against each other in a frequency-dependent fashion (equalizer = can be adjusted) - dampened
- frequency-dependence of amplification is, in turn, modulated by middle ear muscle contractions
- **Active sensing** - directing middle ear bone to better reflect certain frequencies over others
  Perception is an active process. We are equipped to decode certain types of information.

**Inner ear**
- **Cochlea:** fluid-filled, receives vibrations from ossicles
  - (water pressure/movement ⇒ transformed in electrical) through hair cells
- **Semicircular canals:** balance
- transformation of pressure waves (sound) and their frequency characteristics (spectra) into neural signals
Segregation of cochlear ganglion cell outputs to cochlear nucleus according to the position of their hair cell inputs – creation of a topographic representation of sound (tonotopy) that ultimately reaches primary auditory cortex (A1 = Heschl’s Gyrus)

- **Base**: stiff, narrow, dense; high frequency (20K) (vibrated by stapes of middle ear)
  - Basilar membrane decodes: component frequencies & amplitudes
- **Apex**: floppy & wide; low frequency
- A traveling frequency wave displaces a certain point the most along the Basilar Membrane =>
  - Hair cells at this point are stimulated the most strongly =>
  - Nerve fibers fire the most strongly at this location
- You can tell what frequency it is based on where it vibrated the Basilar Membrane the most, therefore certain parts of the BM is sensitive to certain frequencies
- We get a . . . Tonotopic Map
  - Cochlea shows an orderly map of frequencies along its length
Auditory object = each instrument has its own complexity (combinations of frequencies and amplitudes)

Cell motility: Cell depolarize → change shape

Characteristic/Preferred frequency = least graded to produce a response (very sensitive)
ascending pathways of the mammalian auditory system

Cochlear Nucleus → Brainstem (Lateral and Medial Superior Olive = tells location of sound through speaking activity)
the ‘where’ of sound

**ITD = Interaural Timing Difference:**
- The difference of arrival sound in one ear to the other
- *No* difference = *equidistant* to each ear
- *Yes* difference = source is to the *side* of observer to some degree
  - Ex: sound coming from right side reach right ear first
- ITD is a **binaural** cue (involves both ears)
- ITD is encoded in **Superior Olivary Nucleus**

**Weakness of ITD:**
- ITD cannot completely disambiguate source of sound when there are a lot of **points in space where ITD is exactly the same**
- Not useful for persistent high frequency sounds (>2000 Hz) as hair cell responses do not oscillate in response to high frequency tones
the ‘where’ of sound

**ILD = Interaural Level Difference**

- The difference in loudness and frequency in one ear and the other
- The head casts an acoustic shadow that changes the loudness and frequency distribution of sound going in each ear
- ILD is best for high frequency sounds b/c low frequency sounds are not attenuated (not weakened) much by the head
  - Low frequency sounds will just go right over the acoustic shadow
- Big ILD w/ high frequency sounds
- Low ILD w/ low frequency sounds
- ILD is encoded in Lateral Olivary Nucleus
- not useful for low frequency sounds as their amplitude is less impacted by the head

**LSO Registers Interaural Level Differences (ILD)**

- Ipsilateral Cochlear Nucleus: Sends an excitatory projection.
- Contralateral Cochlear Nucleus: Sends an excitatory projection BUT first stops at MNTB (Med 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.
Bat echolocation: finding and tracking the location of prey through comparison of sound time signatures

- **Bat’s auditory fovea**: the basilar membrane of a bat has extra space devoted to regions responding to sounds near 60 kHz (in the range of its calls)
- Bats use **long ‘CF’** calls to assess Doppler shift and, in turn, the movement speed of their prey
- Bats use **shorter ‘FM’** sweeps to assess their proximity to their prey
- Prey size can be determined by the **echo amplitude** (closer = louder)
target speed: utilization of changes in pitch of the CF component between call and echo (i.e., detecting the Doppler shift in frequency)
What frequency is the best?

multiple sub-regions of auditory cortex: most contain a tonotopic map – responses to different sound intensities are heterogeneous
### RA/SA chart so far...

<table>
<thead>
<tr>
<th></th>
<th>Transient (rapid adapting)</th>
<th>Sustained/ Persistent (slow adapting)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Somatosensory</strong></td>
<td>Meissner corpuscle</td>
<td>Merkel discs</td>
</tr>
<tr>
<td></td>
<td>Pacinian corpuscle</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hair cells</td>
<td></td>
</tr>
<tr>
<td><strong>Proprioceptive</strong></td>
<td>Muscle spindle afferent</td>
<td>Golgi tendon organ</td>
</tr>
<tr>
<td><strong>Vestibular</strong></td>
<td>Semicircular canals</td>
<td>Otolith</td>
</tr>
<tr>
<td></td>
<td>(relative to the head - angular velocity)</td>
<td>(reflect linear velocity)</td>
</tr>
<tr>
<td><strong>Vision</strong></td>
<td>Magnocellular (rods - detect change)</td>
<td>Parvocellular (cones)</td>
</tr>
<tr>
<td><strong>Auditory</strong></td>
<td>Octopus cells</td>
<td>Spherical bushy cells</td>
</tr>
<tr>
<td></td>
<td>Cochlear ganglion cells</td>
<td></td>
</tr>
</tbody>
</table>