Topics for Today

Week 2, Lecture 1

**Principles:**
- ‘the neuron doctrine’
- ‘the law of dynamic polarization’

Repeat from last week

Week 2, Lecture 2

**Principles:** none
Week 2, Lecture 1

Proprioception
Sensory Organ Receptors

Rods and Cones for Vision

Muscle Spindle for Proprioception

Many different kinds of sensory organs

Each have anatomical features and unique receptors that determine how they transform the information from the environment into electrical signals that will be sent to the brain.
‘All-Axon’ Ganglion Cell

Dorsal Root Ganglion Cell Bodies:

Gathered on both sides of the dorsal spinal cord all the way down the vertebral column

These are the sensory neurons that bring information UP to the brain
Two kinds of muscle:

1. **Extrfusal muscle**
   - The muscle that contracts and pulls on tendons

2. **Intrafusal muscle**
   - Within the extrafusal muscle; senses the *state* of the muscle
   - Uses *muscle spindle afferents* (dorsal root ganglion cell)
Simplest System of the Nervous System

The Knee-Jerk

1. Doctor taps you on the patellar tendon that runs through the quadriceps muscle and connects down on the tibia

- Presses tendon in and bends extrafusal muscle fibers - stretches muscle
- Means intrafusal muscle fibers stretch too
2. The Dorsal Root Ganglion cell (muscle spindle afferent) of the intrafusal muscle has its membrane distorted

- Creates generator potential as muscle spindle becomes stretched

3. If the integration of generator potentials is strong enough, it will fire an action potential that travels all the way to the ventral horn
4. **Ventral horn** has an excitatory connection to the quadricep motor neuron

- These alpha motor neurons (innervating extrafusal muscle) causes the quadricep muscle to contract
  - Does this through acetylcholine creating depolarization
- Leg kicks out!
  - Consequently stretches out hamstring muscle too (it is the antagonist)
5. The same muscle spindle from the quadriceps also synapses onto the hamstring motor neuron by means of an inhibitory interneuron.

- This inhibitory interneuron inhibits the hamstring muscle.
- The quadriceps’s muscle spindle ‘expects’ the hamstring to want to reflex too, so it takes action to avoid this.
This inhibition is not always the case...

If you kick out your leg purposely/intentionally instead of by means of knee-jerk reflex

Then this circuit will NOT automatically inhibit the hamstring muscle

But if it senses that you may hyperextend your leg, it will retract your leg back in
Intrafusal muscle

- The **muscle spindle afferent** (dorsal root ganglion cell)
  - Unmyelinated dendritic ending wraps around the *non-contractile* portion (the sensor portion)
  - If stretched/elongated, it will *transiently* depolarize
**Gamma Motor Neuron**

Excites the *contractile* portion of the intrafusal muscle

Causes it to contract or elongate

**Alpha Motor Neuron** goes to *extrafusal muscle* to create joint movement
Non-contractile portion adjusts in accordance

Causes *muscle spindle afferent* to *transiently* respond as it stretches/elongates

Signals when there is a *change*
The Muscle Spindle Activation by muscle elongation/stretch is modulated by contraction state of the muscle

Muscle Spindle loosened
Elongated arm (stretched out)

Muscle Spindle cramped
Bicep curl
Golgi Tendon Organ: Registers Tendon Stretch (muscle contraction)

**Sustained** response that indicates the joint angle associated with muscle

This proprioceptive mechanism allows you to know your ENTIRE body posture.
Functions of proprioception

- **Joint-Protecting Reflexes (e.g. Knee-Jerk)**
  - Another example: running on a soccer field and landing in a little hole so your quad stretches a little more than expected so you unconsciously readjust

- **Adjustment of Muscle Contraction/Recruitment**
  - Holding up a backpack in your hand with your elbow bent can become too heavy so your body recruits *more* extrafusal muscle

- **Kinesthesia: detection of body position and movement**
  - How postures change across time, like as you throw a baseball

- **Coordination of Motor Commands**
  - Playing violin two different ways

- **Sense of Self**
  - Different than other sensory systems (which sense things that AREN’T YOU)
Dorsal Root Ganglion Pathway to the Brain

1- Dorsal Root Ganglion

2 - Dorsal Root Horn

3 - Synapse for the first time to either of these within the medulla on the dorsal side
   - Gracile Nucleus
   - Cuneate Nucleus

4 - Axon crossover to other side of the brain (reason for contralateral info. pathway)

5- Travels up to the ventral posterolateral nucleus of the thalamus

6 - Finally! The Postcentral Gyrus

Same as Pathway for tactile
Somatosensory Cortex: where *proprioceptive* and *tactile* information integrate

PPC is where information from other systems converge

Posterior Parietal Cortex (PPC)

- Visual
- Auditory
- Others

Primary Somatosensory Cortex (S1)

Secondary Somatosensory Cortex (S2)

- Tactile
- Proprioception
Using Proprioceptive information:

**Encoding Grasp Postures in Posterior Parietal Cortex (PPC) Subregions**

PPC breaks down into different subregions that differ in effector dependence

**AIP subregion**: registration of grasping postures (pertains to hand as effector)

Monkey reaches into cube for an object after seeing it outside of cube
- Needs notion of shape in order to determine hand posture
- Sensor records fine joint angles in AIP
- Similar objects recruit similar postures
Using Proprioceptive information:

Encoding Grasp Postures in Posterior Parietal Cortex (PPC) Subregions

**AIP subregion**: registration of grasping postures (pertains to hand as effector)
- After seeing the object, the monkey knows “this is the posture I’m going to have”
- Movement and visual response happens in same region (neurons can fire as it sees, plans, and/or does the action)
Using Proprioceptive information:

**Encoding Grasp Postures in Posterior Parietal Cortex (PPC) Subregions**

Other subregions:

- **AIP**: registration of grasping postures
- **LIP**: eye movements to particular objects in visual field
- **VIP**: corresponds to ‘personal space’
- **PRR**: (parietal reach region) when hand needs to be moved somewhere
‘Pinocchio Effect’

- Mechanical vibrating device against bicep muscle activates the muscle spindle afferents and “fools” the body that the arm is elongating

- Fingers on nose activate touch receptors

- The tactile and proprioceptive information integrates in your somatosensory cortex and doesn’t make sense!!

How does your brain make sense of this conflicting information?

Fingers on nose + arm “elongating” = nose must be growing
Vestibular System
And
Head Direction Cells
Vestibular system works with the proprioceptive system for ‘self-motion’. But it is unique in that it focuses on orientation relative to gravity and the world.

It is highly impacted by alcohol! When your eyes get to the extreme sides of this test while intoxicated they will twitch back and forth.
Functions of Vestibular System

- **Postural Reflexes**
  - Sensing when you are starting to trip

- **Gaze Adjustment**
  - Continuing to look at someone while you turn your head

- **Assessment of self motion**
  - Path integration: can close your eyes before you walk and can still know where you started from
  - Constantly equating the movement of your head/self-motion with what you see

- **A reason not to get super drunk**
  - May get ‘the spins’ or fail a sobriety test
The ‘Hair Cell’ Receptor

Transduction (converting external info. into electrical signal) of both head movement (vestibular system) and sound waves (auditory system) into neural signals
Stereocilia exist in fluid environment and its body is embedded in ‘supporting cells’

Like a neuron, they have intracellular and extracellular space with different ion concentrations

(Different from a neuron in that K+ concentration is greater on the outside- or extracellularly)
Depolarize when there is an influx of K+ as the tendril pulls ion channels open

They don’t have action potentials

Rather, depolarization is directly correlated to amount of open ion channels

Hyperpolarized
When pushed towards the shortest because more ion channels are closed

Upright
Most of the ion channels are closed

Depolarized
When pushed towards the longest because the tendril opens ion channels
The Inner Ear
This bony apparatus is fixed to the rest of the skull with the Vestibular Organ that has hair cells inside.

Three (3) semicircular canals on each side of the brain - oriented in different ways

Respond transiently

*NOT SHOWN HERE* Otolith Organ ---- See next slide
Orthogonal orientation of the semicircular canals and otolith organs

The Inner Ear Cont.
The **otolith organ** is composed of
- The Utricle
- The Saccule

Respond **persistently**
Semicircular Canals: registration of rotational velocity

- Endolymph causes movement of cupula
- Endolymph in semicircular canal
- Hair cell: embedded in supporting cell
- Crista ampullaris
- Movement of semicircular canal with body movement
- Fluid environment with higher K+ concentration
Semicircular Canals: registration of rotational velocity (detect radial motion relative to trunk)

When your head moves, it causes the cupula to bend

Ex. Moving a glass of water quickly to the right will cause the water to ‘lag’ and slosh over to the left, but as you stop moving the glass, the water will ‘catch up’ and settle
Semicircular Canals: registration of rotational velocity (detect radial motion relative to trunk)

They are organized as opposites on the left and right side of the head.

As the head moves right and both cupula are pushed to the left:

- **LEFT Side Inhibition**
- **RIGHT Side Excitation**
Otolith Organs: registration of static head position (relative to ground/gravity)

Endolymph is capped by a **gelatinous cap** that has the **otoliths** atop it.

When you tilt your head linearly (relative to the ground/gravity), gravity pulls on this cap.

There are two types of otolith organs:
1. Utricle
2. Saccule
Otolith Organs: registration of static head position (relative to ground/ gravity)

**Utricle**
- Measures movement horizontally

**Saccule**
- Measures movement vertically
Semicircular Canal vs. Otolith Organs (Utricle & Saccule)

registration of rotational velocity of the head (about the trunk) via the semicircular canals

registration of linear translation and static head position via the otolith organs, the utricle and saccule
Vestibular Afferents: Pathway to the brain and spinal cord

The axons of these ganglion cells reach first into **vestibular nucleus complex** in brainstem
- Composed of several subregions
- Don’t worry about different components

From here, projects down to ventral horn of spinal cord to allow for quick righting reflexes

Also projects into cerebellum, oculomotor centers, and parietal cortex
- Has a wide influence
Integrating vestibular signals:

**Vestibulo-ocular Reflex**

Adjusting and maintaining gaze during head movements

If you rotate your head to the left

But want to maintain your line of sight

Your eyes must counter-rotate to the right
Vestibulo-ocular Reflex

Integrating vestibular signals:

Adjusting and maintaining gaze during head movements

Contracting **Rectus Lateralis**
- In left eye, will move eye left
- In right eye, will move eye right

Contracting **Rectus Medialis**
- In left eye, will move eye right
- In right eye, will move eye left

Recall:
- Lateral = outside
- Medial = middle
Vestibulo-ocular Reflex

Integrating vestibular signals:

Adjusting and maintaining gaze during head movements

4. **Rectus Lateralis** for left eye and **Rectus Medialis** for right eye will be activated to control the leftward eye movement
   - Opposite will be inhibited

3. Vestibular Nuclei innervate neurons that project directly to eye muscles, such as **nucleus abducentes**

2. Hair cells (in semicircular canals) on the right are excited while those on the left are inhibited

1. Rotate your head to the RIGHT
Integrating vestibular signals:

‘Head-Direction’ Neuron

Head Direction Cells exhibit firing that correspond to head direction relative to the world instead of the body.

Each cell is ‘tuned’ to have a preferred direction that will fire whether your whole body is facing that way or only your head is oriented in that direction.
Integrating vestibular signals:

‘Head-Direction’ Neuron

Neurons that start to integrate information from Semicircular Canal and Otolith Organ
- Sensitive to angular velocity (the faster you move, the more these neurons fire)

Where head direction cells were first discovered

Get input straight from the visual cortex that allow you to observe landmarks (i.e. using Geisel library to know where you are)
What has the most highly tuned, cleanest response fields in the brain?
What has the most highly tuned, cleanest response fields in the brain?

Head-Direction Cells
<table>
<thead>
<tr>
<th>System</th>
<th>Type of Receptor</th>
<th>Info. Processed/Best Stimulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tactile System</td>
<td>Hair Receptor (RA)</td>
<td>Hair displacement</td>
</tr>
<tr>
<td></td>
<td>Pacinian Corpuscle</td>
<td>High freq. Vibration (e.g. surgeon cutting skin)</td>
</tr>
<tr>
<td></td>
<td>Meissner Corpuscle</td>
<td>Low freq. vibration (e.g. banana <em>slipping</em> out of hand)</td>
</tr>
<tr>
<td></td>
<td>Merkel Disk (SA)</td>
<td>Fine Texture Discrimination (e.g. Braille)</td>
</tr>
<tr>
<td>Proprioceptive System</td>
<td>Muscle Spindle</td>
<td>Signals a change of state in muscle</td>
</tr>
<tr>
<td></td>
<td>Golgi Tendon Organ</td>
<td>Indicates the angle/posture of muscle</td>
</tr>
<tr>
<td>Vestibular System</td>
<td>Semicircular Canal</td>
<td>Registers rotational velocity of head</td>
</tr>
<tr>
<td></td>
<td>Otolith Organ - Utricle</td>
<td>Registers head movement horizontally</td>
</tr>
<tr>
<td></td>
<td>Otolith Organ - Saccule</td>
<td>Registers head movement vertically</td>
</tr>
</tbody>
</table>
The neurotransmitter GABA is:

a) is inhibitory

b) opens Cl- channels

c) is excitatory

d) is a neuromodulator

e) depolarizes postsynaptic targets

f) A and B

g) C and E
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The ‘Pinocchio Effect’ involves a resolution of contradictory information supplied by which two sensory systems of the brain?
The ‘Pinocchio Effect’ involves a resolution of contradictory information supplied by which two sensory systems of the brain?

Somatosensory (tactile) and proprioception

The muscle spindle afferents are activated in the bicep from the vibrating mechanism, while the finger touching the nose activates touch receptors.

Brain’s solution is that the nose must be growing in order to allow you to touch your nose while your arm extends.
Choose the correct term

Generator Potentials are analogous to [synaptic]/[action] potentials?
Choose the correct term

Generator Potentials are analogous to [synaptic]/[action] potentials?
True or False:

Hats sometimes push on and hold hairs of the head in particular positions. The ‘hair’ type of touch receptor provides the brain with a steady indication of these positions.
True or False:

Hats sometimes push on and hold hairs of the head in particular positions. The ‘hair’ type of touch receptor provides the brain with a steady indication of these positions.

‘Hair’ receptors are transient (RA) so they do not provide a steady indication, they signal when there is a change.
‘Microslip’ events are best detected by the ___________ touch receptor.
‘Microslip’ events are best detected by the **Meissner Corpuscle** touch receptor.

Meissner detects low freq. vibration, like a banana microslipping out of your hand

Think: If this slips, it will be *Messy*, so it must be *Meissner*
Vestibular System has two functionally different structures that register the movement and static position of the head.

__________ registers rotational velocity of the head, whereas ____________ registers the linear translation and static head position.
Vestibular System has two functionally different structures that register the movement and static position of the head.

Semicircular Canals registers rotational velocity of the head, whereas Otolith Organ registers the linear translation and static head position.