TA Evaluations

tinyurl.com/wi18-cogsci-evals
COGS 107B – Systems Neuroscience

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Fri 11:00-12:50 CSB 005
OH: Fri 9:00–11:00 CSB 232
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3/9/18
Today’s Schedule

1. Lecture 13: Motor Control
2. Lecture 14: Prefrontal Cortex
Lecture 13: Motor Control

Principle of the week:
**The Population Code**: Patterns of activity occurring over many neurons.

5 minute Video on Population Codes:
http://www.youtube.com/watch?v=7hiGHC_6Nps
Alpha Motor Neurons in Spinal Cord

- Located in the **ventral horn of spinal cord**.
- Receive info from motor cortex.
Alpha Motor Neurons in Spinal Cord

- Alpha motor neurons form endplates (synapses) on muscle fibers where excitation leads to ACh release.
- ACh binds to ionotropic nicotinic receptors.
- Myosin and Actin cause muscle to contract.
Motor Neurons in Spinal Cord

One alpha motor neuron projects to a single muscle but within that muscle, it will synapse on many motor fibers of the same type.
### Muscle Fibers

<table>
<thead>
<tr>
<th>Slow-Twitch</th>
<th>Fast-Twitch</th>
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<tbody>
<tr>
<td>50ms to peak force</td>
<td>25ms to peak force</td>
</tr>
<tr>
<td>Small force</td>
<td>Large force</td>
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<tr>
<td>Non-fatiguing (Aerobic)</td>
<td>Fatigue easily (Glycolysis)</td>
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<tr>
<td>Useful for tonic movements.</td>
<td>Useful for quick, powerful movements.</td>
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Muscle Synergies

- Activation/Inactivation patterns of muscles at any given time.
- Analogous to population code if you look at what muscles are active or inactive, you might be able to tell what action an individual is executing.
Muscle Synergies

Muscle synergies: Patterns of activation and inactivation of muscles at particular times during a movement.

activation / inactivation patterns of muscles at any given time are ‘synergies’ (e.g., knee and hip extensor muscles contract while ankle and knee flexors relax at time given by red arrow)
Motor Neuron and Interneuron Systems in Ventral Horn of Spinal Cord

1) **Corticospinal**: Motor cortex output. Actions that are volitional.

2) **Rubrospinal**: receives output from cerebellum. Cerebellar reflexes.

3) **Vestibulospinal**: Reflexive actions. No cortical engagement.

4) **Reticulospinal**: Fixed action patterns (FAP) Mesencephalic locomotor regions (Brainstem).
Fixed Action Patterns (FAP)

- Common, repeatedly utilized behaviors are controlled by central pattern generators.
- Circuits in brainstem that have genetic prewiring.
- Examples: Walking, chewing, withdrawing from flame.
Properties of Spinal Cord Interneurons

1) Excitatory or inhibitory.
2) Interconnected with themselves and motor neurons.
3) May have axons that cross the commissure and/or extend into other segments.
4) Receive both converging and diverging motor cortex inputs.
Divergence of Corticospinal Axons

A single motor cortex neuron projects to the ventral horn of spinal cord and contacts many different motor neurons that control different muscles.

Axon terminals of a motor cortex neuron innervating four motor neurons in ventral horn of spinal cord.

AP in one Motor Cortex neuron

Contraction of four muscles

Motor cortex neuron

Motor Neuron #1

Motor Neuron #2

Motor Neuron #3

Motor Neuron #4

Muscle #1

Muscle #2

Muscle #3

Muscle #4

spike-triggered recordings of six muscles of the forearm

Muscles:
- Muscle #1
- Muscle #2
- Muscle #3
- Muscle #4

Neurons:
- Motor Neuron #1
- Motor Neuron #2
- Motor Neuron #3
- Motor Neuron #4
Convergence of Corticospinal Axons

Neighboring regions of motor cortex project down and converge onto single spinal cord motor neurons.

Motor Cortex Neuron #1 → Motor Cortex Neuron #2 → Motor Cortex Neuron #3 → Motor Cortex Neuron #4 → Motor Neuron #1 → Muscle #1

neighboring regions of motor cortex (e.g., thumb and forefinger)

projections of motor cortex neurons converge onto single spinal cord motor neurons (e.g., ‘thumb’ and ‘forefinger’ regions of the motor homonculus may form synapses on the same motor neuron)
How does cortical output control muscles?

Eight different directions joystick can be moved

Burst of speed as animal moves the joystick.

Activation of triceps as movement is executed in each of 8 directions.

Activation of posterior deltoid as movement is executed in each of 8 directions.

Examples of muscle synergies

One Motor Cortex Neuron

This neuron fires the most action potentials when the animal pulls the joystick down and to the right.

One Hundred Motor Cortex Neurons for Each of the 8 Directions

Preferred direction of each neuron is pointed by the direction of line and magnitude of neuron's firing by the length of the line.

The pattern of activation unique to each direction, population code, allows you to make an educated guess on the direction of movement.
Premotor cortex drives activity patterns in motor cortex and is, in turn, driven by both prefrontal and parietal cortices.
Neurons in Pre-Motor Cortex I

Premotor cortex in navigating rats exhibits more abstract relationships to actions.

**Sequence-Dependent Action Mapping**: this neuron fires after the last turn if it’s a right turn.

**Action Planning**: this neuron fires during forward locomotion preceding right turns.

**Action Mapping**: this neuron fires during the execution of any right turn.
Neurons in Pre-Motor Cortex II

Activity may reflect the position of an action in an action sequence.

- Activity of a single premotor neuron which fires over the final segment / action irrespective of the direction of movement.

- Activity of a single premotor neuron which fires over the first segment / action irrespective of the direction of movement.
Mirror neurons: Fire when you observe, hear, or execute an action.

right: a neuron in premotor cortex fire during grasping AND as the monkey watches someone else do the same thing

below: a neuron in premotor cortex fires when the monkey breaks a peanut (M), when he sees and hears someone else do the same (V+S), when he only sees it (V), and when he only hears it (S)

below-right: a neuron in premotor cortex fires when an object is grasped even if the object is hidden by a screen (but known to be in place)
Lecture 14: Prefrontal Cortex

- Personality
- Planning
- Decision-making
- Inhibition, self-control
- Attention
- Abstract features of motor task
- Damage to PFC: Phineas Gage.
Premotor cortex – A More Indirect Role in Motor Control

1. Activity, as in primary motor cortex, may directly reflect present action

2. Activity accompanies actions as well as planning for actions

3. Action-related activity may depend on ordering of actions in a sequence

4. Activity may reflect perceived actions as opposed to actual movements (as in ‘mirroring’)
Main point: Dorsolateral PFC fires to more abstract features of tasks.

- Beginning and end of behavioral episodes.
- Time intervals.
- Count/Numerosity
- Extract action sequences categories
Beginning and End of Behavioral Episode

First burst when T1 appears indicates beginning of an episode.

Extra burst in activity after last target (T4) indicates end of episode.

Fujii and Graybiel, Science, 2003
**TASK:** monkey gets cues of different colors which indicate time interval to wait before releasing a key

**PREFRONTAL NEURONS:** individual neurons respond for different cued time intervals – some build responses leading to key release time (below), some decrement responses following cue onset (above).

Cue + delay properties: Burst when cue comes on and then sustained activity.

Memory: Info about how long it has been.
TASK: monkey gets cues of different colors which indicate time interval to wait before releasing a key

 PREFRONTAL NEURONS: individual neurons respond for different cued time intervals – some build responses leading to key release time (below), some decrement responses following cue onset (above)

 Delay + action properties: Increasing activity until the animal releases the key.

 Action: Info to motor areas to release the key.

Mita et al., Nat. Neuro., 2009
**TASK:** monkey gets sample image with 1-5 dots of varying size – delay – test images are given – one has the same number of dots, the other a different number (arrangement and size of dots varies) – monkey must select the one matching the sample image

**PREFRONTAL NEURONS:** exhibit delay activity specific to particular dot ‘counts’ irrespective of their size or arrangement

There are neurons in the PFC that are tuned to a particular number of objects.
TASK: monkey observes a four-item sequence wherein three buttons (push, pull, turn) are lit in different combinations – monkey must remember the sequence and then perform it

 PREFRONTAL NEURONS: have delay activity that corresponds to one of three ‘categories’ of action sequence (AABB, ABAB, AAAA)

<table>
<thead>
<tr>
<th>Neuron 1</th>
<th>Neuron 2</th>
<th>Neuron 3</th>
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<tbody>
<tr>
<td>A A B B</td>
<td>A B A B</td>
<td>A A A A</td>
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<table>
<thead>
<tr>
<th>Push</th>
<th>Pull</th>
<th>Turn</th>
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Shima et al., Nat. Neuro., 2007
Top-Down Influence to Other Regions of Cortex

1. Direct projections
2. Projections to neuromodulatory systems
3. Projections to thalamus

- Prefrontal cortex
- Basal forebrain ACh
- Locus coeruleus NE
- Substantia nigra/VTA DA
- Raphe 5-HT

- Thalamus
- Premotor cortex (motor planning)
- Parietal cortex (visual ‘where’ pathway)
- Inferotemporal (IT) cortex (visual ‘what’ pathway)
- Premotor cortex (motor planning)

Top-down influence to other regions of cortex.
an example: prefrontal ‘top-down’ influences on parietal cortex during an oculomotor delayed response task – inactivation of prefrontal cortex via cooling depresses ‘working memory’ responses of parietal cortex neurons and increases errors

parietal neuron has delay-period activity specific to the N and NW targets

Sustained activity during delay period.

delay-period activity for the same neuron is depressed when prefrontal cortex is inactivated

Lower delay activity = errors.

Chafee and Goldman-Rakic, JNP, 2000

PFC exerts top-down influence on parietal cortex, controlling working memory for this task.
task: single visual cue (the target) is given followed by a delay – then two stimuli (one the target cue) are shown and the monkey saccades to the target cue –

premise: IT neurons have activity specific to particular objects during the cue phase – is their object-specific activity subject to the effects of attention?

Main point: The animal’s attention modulates the firing activity of the cell.
Attention goes to poor stimulus → firing rate drops
Attention goes to preferred stimulus → firing rate is sustained.
Lectures 11-14 Resource Questions

The following slides were provided by Joey Relaford-Doyle.
Do you know your principles?

fire together – wire together:
This pertains to the idea that the strength of a connection between a presynaptic and postsynaptic neuron (measured by examining the degree of ______________ in the postsynaptic neuron resulting from a single ______________ in a presynaptic neuron) can change (i.e., wire together) as a function of whether or not the two neurons are ______________ (i.e., fire together)

depolarization  
action potential  
co-active

implicit vs. explicit memory:
There are many types of memory (associative, procedural, declarative, episodic, working). For some types (_______________), it is possible to consciously know the content of the memory (for example, the sky is blue or “I ate breakfast at Denny’s this morning) while, for ______________ memory, it is not consciously known what the memory is exactly (as in ______________ memories like remembering how to swim – a motor skill memory).
the population code:
This pertains to the idea that perceptions (e.g., awareness of present spatial position) and actions are both realized by _______patterns_______ of activity among large populations of neurons as opposed to activation of single neurons. With respect to the motor system, the ____________Population firing rate vector__________________________ (a list of the firing rates for a large set of motor cortex neurons) bears direct relation to the present on-going action (itself a pattern of muscle ______synergy______).

top-down processing:
This pertains to the idea that structures such as the ______prefrontal cortex_________ cortex may, to some extent, control or bias activity patterns in other brain structures. There are three pathways by which the pre-frontal cortex can enact top-down influence on other cortical regions: through ______direct_________ projections, via the ______thalamus________________________, or through the brain’s ______neuromodulatory_________ systems.
1. Synaptic efficacy changes can occur through a number of mechanisms. Name two that pertain to the physical structure of axons and/or dendrites.

   Development or retraction of synapses
   Shape of synapse
2. In what state might decreases in synaptic efficacy occur irrespective of the ordering of firing of the presynaptic and postsynaptic neuron?
   (a) Texas  
   (b) waking  
   (c) NREM sleep  
   (d) REM sleep
3. True/False: Increased ACh release in the hippocampus favors expression of a procedural memory.
4. The spatial and episodic memory functions of the hippocampus are made compatible because of these two forms of spatial position coding.

Retrospective, Prospective
5. True/False: Individual motor neurons of the ventral spinal cord synapse upon both slow-twitch and fast-twitch muscle fibers.
6. Name the term used to describe activation patterns across the musculature that allow coordinated action and which are encoded through the activity of motor cortex neurons.

Muscle synergy
7. Premotor neurons are involved in which of the following features of motor control?

(a) execution of an action
(b) planning an upcoming action
(c) perception of an action
(d) mapping of actions according to position in a sequence
8. True/False: Top-down attention is mediated by the parietal cortex.
9. Name two of the four features of behavioral tasks that prefrontal neurons were shown to map through their activity patterns.

- Marking beginning/end of episode
- Count/numerosity
- Time intervals
- Categories