COGNITIVE SCIENCE
107A

Motor Systems: Cerebellum

Jaime A. Pineda, Ph.D.
CEREBELLUM
(small brain)
Functions: Motor Learning and Coordination

- Combines and coordinates rapid, skilled movements
- Controls and corrects compound, complex movements through feedback and timing
- Gains control through trial-and-error (error-correction or supervised learning network)
- With time and practice control passes from effortful to effortless
- Effects on equilibrium, posture, and muscle tone
Functions: Cognition

- Learning
- Cognitive processing of words
- Anticipatory planning
- Making time-based judgments

*Ideas and concepts are manipulated in thoughts in the same way that limbs are manipulated in movement*
Cerebellar Damage

- Initial state of rigor
  - Inhibits muscle contractions
- Rigor subsides
- Inaccurate and exaggerated movement (dysmetria:hypo/hyper)
- Incoordination (ataxia)
- Hypotonia
- Intention tremors (start/stop problem) during volitional movements
Effects on Cognition

• PET AND fMRI activation
  – Imagined or passively observed movement
  – Verb generation task
    • CAR $\rightarrow$ DRIVE
  – Decreased activation when task is well-practiced
  – Connections to prefrontal cortex
Figure 1:

In *supervised learning*, a *detailed target output* is given for each *input* and the *goal* of learning is to *minimize the error signal*. In *reinforcement learning*, no *explicit target output* is given, but a *scalar reward signal* is given that notifies how good or bad the *output* (or a sequence of outputs) was. In *unsupervised learning*, no target or reward signal is given and the *output* is determined to best represent the statistical features in the *input*. 
FIGURE 42-3
The basal ganglia and cerebellum are major components of two subcortical feedback loops of the motor system, but differences in their anatomical connections suggest they have different functions.
A. Connections of the basal ganglia.
B. Cerebellar connections.
## Inputs and Outputs

<table>
<thead>
<tr>
<th>Peduncle (little feet)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Superior</strong></td>
<td><strong>Output</strong> (0.8 M)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Middle</strong></td>
<td><strong>Input</strong> (20 M)</td>
</tr>
<tr>
<td></td>
<td><strong>Mossy fibers</strong></td>
</tr>
<tr>
<td><strong>Inferior</strong></td>
<td><strong>Input</strong> (0.5 M)</td>
</tr>
<tr>
<td></td>
<td><strong>Climbing fibers</strong></td>
</tr>
</tbody>
</table>
Interposed
(Emboliform,Globose)

INTERMEDIATE

Fastigial

VERMIS

Dentate

“Don’t Eat Greasy Food”

LATERAL

Primary fissure

Anterior
regulates posture

Posterolateral fissure

Posterior
fine motor coordination

Flocculonodular
equilibrium

Left hemisphere

Right hemisphere
Thalamus, Spinal cord  
Red nucleus  
**Interposed**  
(Embolicform,Globose)  
INTERMEDIATE  
VERMIS  
LATERAL

Spinal cord, Medulla, Pons, RF, Vestibular n.  
Fastigial  
**Dentate**  

Motor cortex  
Thalamus  

Proprioceptive, somatosensory  

motor, premotor, other ctx  

vestibular
Accuracy of posture, locomotion, gaze (trunk, leg, head, and eye movement)

Interposed (Emboliform, Globose)

Accuracy of voluntary movement

Fastigial

Thalamus

cognition

Dentate

INTERMEDIATE VERMIS LATERAL

Proprioceptive, somatosensory

motor, premotor, other ctx

vestibular
Cerebellar Cortex

- 3-layered cortex*
- Made up of 7 types of neurons
  - Purkinje cells(-)
  - Granule (+)
  - Unipolar brush (+)
  - Golgi (-)
  - Lugaro (-)
  - Basket (-)
  - Stellate (-)

* Shows 6 layers early in development and 4 at birth
Purkinje Cell
Principal neuron
Purkinje Cell

- 15 million in human cerebellum
- 2-D
- Extensive arborization
  ~200,000 spines
- Inhibitory (GABA)
- Project to deep nuclei
- Fires ‘simple’ spikes (30-50 Hz) in the absence of input and with MF/PF (cortex) input
- Fires ‘complex’ spikes with CF (sensory) input
- Simultaneous inputs (CF and MF/PF) produce LTD
- MF/PF input alone produces LTP (non-NMDA mediated since no NMDA receptors in cerebellum)
Granule Cells

- 50 billion or more
- 3-5 dendrites
- Excitatory (GLU)
- Axon bifurcates (creating parallel fibers)
- Unmyelinated axon (with varicosities)

6-8 mm
Cerebellar Inputs

- Two input pathways
  - Mossy fibers (cortex): contact granule cells with a collateral to deep nuclei; excitatory (GLU) (MF state vector)
  - Climbing fibers (spinal cord/brainstem): contact Purkinje cells with a collateral to deep nuclei; excitatory (CF state vector: training/error signal)

~150K PF synapses per Purkinje cell
BASIC GLOBAL CIRCUITRY

Prefrontal CTX
8, 44, 45

Supplementary Motor CTX
9

Pre Motor CTX
6

Primary Motor CTX
4

Thalamus
VA/VL

PONTINE NUCLEI

Red nucleus

INFERIOR OLIVE

Spinal cord

CEREBELLUM

Mossy fibers

Deep nuclei

Climbing fibers

Granule cell layer

Purkinje cell layer

Molecular layer
A Hypothesized Function

• Compare two patterns of nerve discharges in time arriving at Purkinje cells through two different inputs (mossy and climbing fiber inputs)
• Determine the appropriate combination of muscles that need to be inhibited in the on-going program (LTP and LTD)
• Determine the appropriate combination of muscles that need to be activated for the new program (communicated to deep nuclei)
• Deep nuclei execute a transfer function which sends the “how-to-change-from-old-to-new” commands to cortex which then executes it and provides feedback.