Cogs17 Neurobiology of Cognition

Lecture 7: **Control of Movement**

Muscles Three types Smooth (internal organs), Cardiac (heart, endogenous activity) and Striate (Skeletal, Facial)

Striate: Band of parallel fibers, each fiber made of many cells but acts as unit; Attached by tendons to bones;

- Come in Antagonistic Pairs: **Flexor** moves bone toward body, **Extensor** move same bone from body

Neuro-Muscular Junction (primarily involving Striate Muscles);

- Motor Neurons ("Alpha Motor Neurons") exit Ventral Root of Spine >> Striate muscles
- Neuron synapses directly onto muscle, releasing **Acetylcholine** (ACh), always sufficient to trigger response
  - Usually 1 axon branches to multiple muscle fibers; the fewer fibers per axon the more precise the control
- Like in a neuron, Muscle fiber response is all/nothing depolarization => Na+ and then K+ gates open/close
  - Ca++ enters muscle cells => triggers energy-requiring process that causes muscle contraction (See below)
  - Afterward, Ca++ is actively pumped out, and a Na+/K+ Pump repolarizes fiber for next contraction

Contractile Mechanism - Within each fiber is a string of **Sarcomeres** (the contractile units) each consisting of….

Myosin = thick protein filament with knobby bead-like clusters ("Cross Bridges") along it, and

Actin = thin protein filament, a coiled double-strand braid, anchored to muscle

- Contraction = Myosin Cross Bridges hook into (grab) coiled Actin, bend to tighten coil, release, repeat
  - So note, the only active muscle response is contraction – all stretch is passive.

Reflexes – Most involve Spinal Cord circuits (i.e. without brain participation)

Stretch Reflex - Proprioceptors called **Spindles** in muscle detect passive stretch of muscle
(e.g. while walking, lifting, being tapped on knee by a doctor "testing your reflexes", etc.)

- Axon of Spindle to Spinal Cord, excites Motor Neuron back to same muscle, contracts to counter stretch
  - Note: this is the only "mono-synaptic" reflex

Golgi Reflex - Proprioceptors called **Golgi Tendon Organs** in tendons detect intensity of muscle contraction

- If contraction is too strong (threatens to tear muscle apart) sends signal to Interneurons in Spinal Cord that **inhibit** the Motor Neurons causing that contraction, lessening their rate of firing
- Note that since striate muscles come in antagonistic pairs, inhibiting a given flexor usually also involves a parallel circuit to excite its paired extensor (and inhibiting extensor involves exciting its flexor)

Pain Withdrawal Reflex - e.g. Touch a hot stove => jerk hand away

- Stimulated Nociceptors signal Interneurons in Spinal Cord to **excite** Motor Neurons that synapse back onto relevant Flexor muscles to move body part way from noxious stimulus
- Note: Signals sent along myelinated Motor Neurons reach muscle before Pain signal even reaches brain

Scratch Reflex - e.g. Dog's rhythmic scratch with hind leg = an **Oscillator Circuit** (as for human "raspberry")

- Rate is relatively fixed, mediated by Spinal Cord (remains the same even if cord severed from brain)
- Such Oscillator circuits, produced by **Central Pattern Generators**, in Cord, Cerebellum, & elsewhere, in humans probably involved many learned "motor programs" including dance, speech, writing, etc.

Infant Reflexes - e.g. "Rooting" (touch to cheek => turn head & suck) & "Grasping" (tough hand => grab, can actually support weight for first few days of life, then lose, vestigial from furry primate ancestors)

- These can reappear in drunken (or brain damaged) adults! In part mediated by Cerebellum

Pathways There are MANY complex motor pathways. Two major ones are…

Cortico-Spinal ("Pyramidal") **Tracts**; mainly to **Contra-Lateral** Periphery, crossover at Pyramids of Medulla

- Large Pyramid Cells from Motor Cortex, synapse in Spinal Cord (onto Inter-Neurons or Motor Neurons)
  - Some synapse first at **Red Nucleus** (e.g. integrate w/Vestibular & Cerebellar info) then most to Cord
  - Fast, myelinated tracts, esp. for precise control of peripheral movements (e.g. hands, fingers, limbs, + face)
- Also includes to face, cross over in Pons, synapse on cranial (Trigeminal) nerve to face

Ventro-Medial Tracts; Mainly for **Bi-Lateral** Midline control (both sides of central body & co-ord'd limbs)

- Multiple sub-paths, originating from sub-cortex, most synapse in Spinal Cord, esp on Inter-Neurons
  - Many make multiple connections in Tectum, Vestibular Nucleus, Reticular Formation, then to Cord
- These pathways are primarily **Ipsi-lateral**, (though some collaterals crossover in Brain Stem)
  - Primarily controls posture, movement of neck, shoulders & trunk, esp in co-ord with sensory activity (e.g. head/eye movement) & gross body movement (walking) – Note all involve both sides at once

Cerebellum "Little Brain", 13% of brain mass, contains more neurons (~50 billion) than rest of brain combined!

- We are still discovering functions of this massive info-processing structure!
- For rapid, coordinated and/or **ballistic** movements requiring precise **aiming and timing** = "Motor Programs"
  - e.g. Saccades = Ballistic "jump" of eyes from one focus point to another (once begun, cannot stop)
  - e.g. Learned (well-practiced) behaviors, from simple clapping to complex athletic or manual activities

- e.g. Judging/responding to speed of moving stimuli, auditory intervals, timing of cued **attention shifts** etc.
- Frequently depend on ongoing sensori-motor feedback, often executed w/minimum cognitive intervention

- Receives proprioception from Spinal Cord & sensory info (esp Visual and Vestibular) via Cranial Nerves
  - Also from Cortex about planned & initiated movements; It computes details of required muscle outputs
- Projects to all major motor structures in brain; including Ventrolateral Thalamus (**VLN**) to Cortex
  - *No* direct projections to Motor Neurons; Influences signals sent along above Tracts to Cord
- In Cerebellar Cortex, **Parallel Fibers** like wires along long rows of "telephone poles" called **Purkinje Cells**
  - Action potentials in Parallels travel along, exciting Purkinjes, who send Inhibition down to **Deep Nuclei**
  - Deep Nuclei, when released from Inhibition, spontaneously command motor nuclei in brain
    - e.g. Ultimately activating antagonistic muscle groups to start/stop each particular movement
  - Thus, **timing** of such outputs is **coded per distance** the signals travel along the Purkinjes
- Cerebellar neurons are particularly sensitive to alcohol
  - Sobriety tests include cerebellar-controlled actions like walking a straight line, touching finer to nose, etc.

Basal Ganglia (**BG**) Complex set of large subcortical structures

Organizes Behavior, esp (tho not only) learned, task-based sequences

- Includes **Caudate Nucleus, Putamen, Globus Pallidus, Claustrum**, all of which exchange info with each other
  - Caudate Nuc + Putamen (AKA "**Striatum**") mainly *receive* sensori-motor from Thalamus, Tegmentum, & Cortex
  - Globus Pallidus *sends* output up to Motor Cortex via Thalamus, and down via Red Nucleus to Cerebellum & Cord
  - Claustrum, just sub-cortical to Insula, connects w/Cortex, esp Frontal & Sensory (Topo map of Sensory Cortex!)
- Note: Basal Ganglia a "Re-entrant" system, cycling info from Cortex to Sub-Cortical structures & back again

Motor and More!

- Involved in direction and amplitude of slow, smooth-changing, voluntary movements (e.g. **posture, walking**)
  - Pathology includes Parkinson's Disease (see below)
- May also be implicated in "**automating**" complex sequential processes (e.g. driving) & in "**selecting"** use
  - i.e. Use stored information to guide use; Produce habit when discern that conditions are met, etc.
- Overactive links with Prefrontal Cortex => Obsessive-Compulsive Disorder: repeat behavior, no task satisfaction
  - Other Prefrontal links implicated in Attention Deficit Disorder (ADD): difficulty in staying on task
- Also has direct connections with Limbic System, including Amygdala (Emotion) & Nucleus Accumbens (Reinf)

Parkinson's Disease

- Symptoms: rigidity, tremors, difficulty in initiating/stopping movement, memory & other cognitive deficits
- Primarily from degeneration of **Dopaminergic** axons from especially **Substantia Nigra** (Tegmentum) to Striatum
  - Result: Increased inhibition from Globus Pallidus to Thalamus, decreasing Thalamic excitation of Cortex
- Treated primarily by **L-dopa**, Dopamine precursor that crosses Blood-Brain barrier
  - Reduces symptoms but does not prevent continued neural degeneration; can have serious side effects
- Some traced to environmental toxins (pesticides); Ingest MPTP, converted to MPP+ =>accumulates in S.N.

Motor Cortex

- **Primary Motor Cortex** in Frontal Lobe on **Precentral Gyrus** just anterior to Central Sulcus
  - Includes topological "Map" of body; Receives from corresponding map in nearby Somatosensory Cortex
  - No direct connection to muscles, but send commands to Motor Neurons in Brain Stem and Spinal Cord
- **Secondary Motor Cortex** Involved in Planning movement. Includes:
  - **Premotor Cortex** in Frontal Lobe anterior to Primary Motor Cortex
    - Active during "preparation to move", just preceding Primary Motor Cortex activity
    - **Mirror Cell System** w/Visio-Spatial Parietal, responds to seeing own, or other's, hands doing familiar tasks
    - Also includes much of **Broca's Area**, involved in production of grammatical speech (more later)
  - **Supplementary Motor Cortex** in Frontal Lobe anterior to Primary Motor & dorsal to Premotor Cortex
    - Like Premotor, active during preparation, but especially for rapid sequences of movements
    - Receives from Parietal Cortex including somato- (esp proprioceptive) & posterior visio-spatial maps