What's the motor system?

- Parts of CNS and PNS specialized for control of limb, trunk, and eye movements
- Also holds us together
- From simple reflexes (knee jerk) to voluntary movements (96mph fast ball)
- Remarkable: Muscles only contract

Plan

- Components of the motor systems
  - Focus on spinal control of limbs and trunk
  - Same principles apply to head control via brain stem
- Basic principles of movement control
  - What is helpful for understanding basic motor system organization
- Motor programs for voluntary movement
- Descending motor pathways
- Note about motor system’s bad rep…
Functional Hierarchy of Motor Paths

- Cerebral cortex
  - Association and Limbic
    - Basal ganglia
    - Thalamus
    - Brain stem
    - Spinal cord

Voluntary movement sequences
Motor imagery
Individuated finger movements
Motor execution: force & direction

Postural reflexes
Cranial reflexes
Simple patterns
Reflexes

Parallel Organization

- Cerebral cortex
  - Association & Limbic cortex
  - Basal ganglia
  - Thalamus
  - Brain stem
  - Spinal cord
  - Basal ganglia
  - Cerebellum
Hierarchical & Parallel Organization of the motor systems

- Top down organization of the motor pathways—opposite that of sensory paths
- Subcortical motor centers—cerebellum & basal ganglia—access cortical motor areas via the thalamus (not just sensory)
- Organization of multiple subcortical and cortical motor circuits—reminiscent of parallel sensory pathways

Organization of Movements

- Hierarchical: 3 major types
  - Reflexes
  - Postural adjustments
  - Voluntary movements
    - ...from simple to complex
- Diverse & adaptive
  - Purposeful
Organization of Movements

- Hierarchical: 3 major types
  - Reflexes: Spinal cord circuits
  - Postural adjustments: Spinal & Brain stem
  - Voluntary movements: Spinal cord, Brain stem, & cortex

Postural adjustments & voluntary movements depend more on cerebellar and basal ganglia function than reflexes

Dual purpose: 1) upcoming lectures; 2) context for motor pathways

Reflexes

- Stimulus-evoked involuntary muscle contraction
- Monosynaptic (+) reflex
  - Knee jerk
  - Jaw jerk
- Simple neural representation (circuit)

Knee Jerk

From muscle stretch receptors

Ventral horn

to muscle
Reflexes

- Stimulus-evoked involuntary motor muscle contraction
- Monosynaptic (+) reflex
  - Knee jerk
  - Jaw jerk
- Disynaptic reflex (+)
  - Withdrawal

Why Disynaptic?

- Greater control (neural gate)
  - Very simple context
- More complex response

Greater control:
Greater control:
from periphery
from higher centers
to muscle
Response blocked by inhibition

Motor I/O
S ——— R  Knee-jerk

Motor I/O
S ——— R  Knee-jerk
S₁ ——— R₁  Automatic postural adjustments
Sn ——— Rn

- Flexible than reflexes (greater #; each with control)
- Constrained than voluntary

- Balance
- Limb support
Postural adjustments

• Context important
  – Can reorganize depending on context

• Feedback control reactive
  – Error correction
  – Response lags stimulus; sometimes too late; sometimes vicious circle

• Feed forward control predictive
  – Response anticipates stimulus
  – More timely, but depends on practice

• Depends on cerebellum, brain stem pathways & spinal cord
  • More complex neural representation

Voluntary movements

• Organized around purposeful acts

• Flexible input output relationships
  – Limitless
  – Price to pay: whole brain

Voluntary movements

• Organized around purposeful acts

• Flexible input output relationships
  – Limitless
  – Price to pay: whole brain

• Recruits all motor systems components & much of the association cortex

Discuss:
• Goal representation
• Motor programs
The goal of voluntary movements is represented… somewhere

- Motor equivalence
  - Individual motor actions share important characteristics even when performed in different ways
- Abstract representation; effector independent
  - Hand writing
  - Soccer
- Goal representation
- ??Association & **Premotor cortex**

Voluntary movements are organized by motor programs

- Translate goal into action
  - Formation of a movement representation, or motor program
- ??**Premotor cortex** --> **Primary motor cortex**
- Program
  - To produce the desired goal, which muscles should contract and when
- 2 Key movement characteristics that are **programmed**
  - Spatial (hand path; joint angles) **Kinematic program**
  - Force **Dynamic program**

Kinematic & Dynamic Programs in Reaching

- Reach to target—(Sensation to Action)
  - Visual cortex-->Association cortex-->Premotor-->1° motor
- Distinct **kinematic** and **dynamic** programs
  - Reach up
    - Against gravity
    - More force to achieve goal
  - Reach down
    - Gravity assists
    - Less force to achieve goal
    - Flexible control
Summary

- Motor behavior hierarchy
  - Reflexes
  - Postural adjustments
  - Voluntary movements
- Internal/neural representations
  - Reflexes simple; invariant
  - Postural adjustments
  - Voluntary movements complex; flexible
- Voluntary movements
  - Goal representation
  - Kinematic and dynamic programs
  - No wonder why voluntary movement recruit entire motor system
Motor pathways organized around the motor nuclei
Ventral Horn Organization:
Proximal-distal rule

Lateral pathways:
limb control

Medial pathways:
trunk control

Brain Stem Motor Paths

Medial
Lateral

Tectum
Reticular formation
Tectospinal tract
Reticulospinal tracts

Vestibulospinal tracts

Vestibular nuclei

Red nucleus

Rubrospinal tract

Bilateral
Contralateral
Brain Stem Pathways

- **Lateral**
  - Rubrospinal tract: distal limb control; crude

- **Medial**
  - Tectospinal tract: eye-head coordination
  - Reticulospinal tract: automatic postural adjustments and movements (hip; shoulder)
  - Vestibulospinal tract: balance (axial muscles); automatic postural adjustments

Brain stem nuclei

- Superior colliculus
  - Tectospinal tract
- Red nucleus
  - Rubrospinal tract
- Vestibular nuclei
  - Vestibulospinal tracts
- Reticular formation
  - Reticulospinal tracts

Cortical Motor Paths

- Medial
- Lateral
- Bilateral
- Contralateral
- Pyramidal X
- Red nucleus
- Rubrospinal tract
- Ventral corticospinal tract
Cortical motor paths

- Lateral corticospinal tract
  - Limb control mostly
- Ventral corticospinal tract
  - Proximal muscle control; mostly upper body
- For cranial muscle control:
  Corticobulbar tract
  - with medial and lateral components
Why bother study the motor pathways?

- Anatomical substrates: How it works
- Multiple parallel paths & diversity of spinal connections
  - Damage to 1° motor cortex and **pre-motor cortex** projections recover some lost functions
  - Damage to cortex and **brain stem paths** recover some lost functions
  - With spinal cord injury, loss of monosynaptic connections and alternate paths via **segmental** and **intersegmental interneurons** can recover some lost functions