• The brain influences spinal cord
  – Voluntary movements

• Hierarchy of controls
  – Highest level: **Strategy** (ASSC. CORTEX, BASAL GANGLIA)
  – Middle level: **Tactics** (MOTOR CORTEX, CEREBELLUM)
  – Lowest level: **Execution** (BRAIN STEM AND SPINAL CORD)
• Sensorimotor system (too fast?)
  – Sensory information: Used by motor system

**Descending Spinal Tracts**

• Axons from brain descend along two major pathways
  – Lateral Pathways (cortex – voluntary)
  – Ventromedial Pathways (posture, locomotion – brain stem)
Descending Spinal Tracts

- The Lateral Pathways
  - Voluntary movement \(\rightarrow\) under direct cortical control
  - Components
    - Corticospinal tract a.k.a Pyramidal tract
    - Rubrospinal tract
      - (red nucleus)

Lateral corticospinal tract crosses midline
(will move limbs and digits)

Ventral corticospinal tract does not
(will move midline muscles).
Descending Spinal Tracts

- The Lateral Pathways (Cont’d)
  - The Effects of Lateral Pathway Lesions
    - Experimental lesions in corticospinal and rubrospinal tracts
      - Fractionated movement of arms and hands
    - Damage of corticospinal tract
      » Paralysis on contralateral side

The Motor Neurons—and interneurons
located in gray matter of ventral “horn”

Lateral corticospinal tract synapses on motor neurons that move muscles in limbs and digits in contralateral side.

Ventral corticospinal tract synapses on motor neurons of midline muscles (trunk) in ipsi side.

strokes

- Severe immediate deficit
  - Spinal shock – hypotonia

- Reflex recovery (good or bad?)
  - Hypertonia, hyperreflexia
    • CLONUS (CYCLES)
- Babinski sign
Descending Spinal Tracts

- The Ventromedial Pathways
  - Posture and locomotion → under brain stem control
  - The Vestibulospinal tract (HEAD BALANCE)
  - The Tectospinal tract (HEAD RESPONSE)
  - The Pontine and Medullary Recticulospinal tract (MAINTAIN POSTURE)
• WHERE IS YOUR HEAD?

Receptors - also called hair cells - encode location and movement relative to gravity.

The Planning of Movement by the Cerebral Cortex

• Motor Cortex
  – Area 4 and area 6 of the frontal lobe

Visual inputs
MOTOR Homunculus
(little person)

Skilled movement is versatile
(different species use hands, noses, lips)

Wilder PENFIELD (1930s-50s)
maybe not quite so accurate.

Main point
more cortex is devoted to some
specific body parts

Lashley proposed motor sequences
SPEECH examples

1) Prefrontal cortex – plans complex movements,
specifies goal

2) SMA, PMA (6) – produces sequences of movement

3) Primary motor cortex (4)– specifies details of how
movement is carried out

All are frontal lobe actions (anterior to central sulcus)
Cerebral Cortex

- Motor Cortex
- Area 4 = “Primary motor cortex” or “M1”
  - Area 6 = “Higher motor area” (Penfield)
- Lateral region → Premotor area (PMA)
- Medial region → Supplementary motor area (SMA)
- Motor maps in PMA and SMA
  - Similar functions; different groups of muscles innervated

The Planning of Movement by the Cerebral Cortex

- The Contributions of Posterior Parietal and Prefrontal Cortex
  - Represent highest levels of motor control
    - Decisions made about actions and their outcome
  - Area 5: Inputs from areas 3, 1, and 2
  - Area 7: Inputs from higher-order visual cortical areas such as MT
• The Contributions of Posterior Parietal and Prefrontal Cortex

– Anterior frontal lobes: Abstract thought, decision making and anticipating consequences of action
– Area 6: Actions converted into signals specifying how actions will be performed
– Per Roland Monitored cortical activation accompanying voluntary movement (PET)
  • Results supported view of higher order motor planning

Lesion in premotor cortex – cannot organize sequence
The Contributions of Posterior Parietal and Prefrontal Cortex

• Neuronal Correlates of Motor Planning
  – Evarts: Recorded activity in motor areas of awake, behaving animals
    • Demonstrated importance of area 6 in planning movement
    • “ready”– Parietal and frontal lobes
    • “set”– Supplementary and premotor areas
    • “go”– Area 6

The Basal Ganglia

• Basal ganglia
  – Project to the ventral lateral (VLo) nucleus
  – Provides major input to area 6
• Cortex
  – Projects back to basal ganglia
  – Forms a “loop”

The Basal Ganglia

• Function of the loop: Selection and initiation of willed movements
The Basal Ganglia

- Anatomy of the Basal Ganglia
  - Caudate nucleus, putamen, globus pallidus, subthalamic nucleus
  - Substantia nigra: Connected to basal ganglia

The Basal Ganglia

- Anatomy of the Basal Ganglia (Cont’d)
The Basal Ganglia

• The Motor Loop: Selection and initiation of willed movements
  – Origin of direct path: Excitatory connection from the cortex to cells in putamen
  – Cortical activation
    • Excites putamen neurons
    • Inhibits globus pallidus neurons
    • Release cells in VLo from inhibition
  – Activity in VLo influences activity in SMA

The Basal Ganglia

• The Motor Loop (Cont’d)
  – Basal Ganglia Disorders
    • Hypokinesia and hyperkinesia
    • Parkinson’s disease
      – Symptoms: Bradykinesia, akinesia, rigidity and tremors of hand and jaw
      – Organic basis: Degeneration of substantia nigra inputs to striatum
      – Dopa treatment: Facilitates production of dopamine to increase SMA activity

The Basal Ganglia

• The Motor Loop (Cont’d)
  – Basal Ganglia Disorders (Cont’d)
    • Huntington’s disease
      – Symptoms: Hyperkinesia, dyskinesia, dementia, impaired cognitive disability, personality disorder
    • Hemiballismus
      – Violent, flinging movement on one side of the body
BASAL GANGLIA

Cortex

“Indirect” pathway

Putamen

Globus pallidus external

Subthalamic nucleus

“Direct” pathway

Thalamus

Globus pallidus internal

Brainstem, spinal cord

INHIBITS (CONTROLS) THALAMUS

basal ganglia – LINKS motor cortex and midbrain

Cortex

“Indirect” pathway

Putamen

Globus pallidus external

Subthalamic nucleus

“Direct” pathway

Thalamus

strong or weak?

Globus pallidus internal

Brainstem, spinal cord
Initiation of Movement by the Primary Motor Cortex

- Electrical stimulation of area 4
  - Contraction of small group of muscles
- The Input-Output Organization of M1
  - Betz cells: Pyramidal cells in cortical layer 5
  - Two sources of input to Betz cells
    - Cortical areas
    - Thalamus
- The Coding of Movement in M1
  - Activity from several neurons in M1 encodes force and direction of movement
Initiation of Movement by the Primary Motor Cortex

• The Coding of Movement in M1

  – Movement of direct encoded by collective activity of neurons
    • Motor cortex: Active for every movement
    • Activity of each cell: Represents a single “vote”
    • Direction of movement: Determined by a tally (and averaging)

Initiation of Movement by the Primary Motor Cortex

• The Coding of Movement in M1 (Cont’d)

  – The Malleable Motor Map
    • Experimental evidence from rats
      – Microstimulation of M1 cortex normally elicits whisker movement
      – Cut nerve that supplies whisker muscles
      – Microstimulation now causes forelimb movement
    • Decoding M1 activity
      – Helps patients with severe damage to their motor pathways
The Cerebellum

• Function: Sequence of muscle contractions
  – Ataxia
    • Uncoordinated and inaccurate movements
    • Caused by cerebellar lesions
  • Symptoms
    – Dysynergia, dysmetric

The Cerebellum

• Anatomy of the Cerebellum

– Folia and lobules
– Deep cerebellar nuclei
  • Relay cerebellar cortical output to brain stem structures
– Vermis
  • Contributes to ventromedial pathways
– Cerebellar hemispheres
  • Contributes to lateral pathways
The Cerebellum

- The Motor Loop Through the Lateral Cerebellum
  - Pontine nuclei
    - Axons from layer V pyramidal cells in the sensorimotor cortex form massive projections to pons
  - Corticopontocerebellar projection
    - 20 times larger than pyramidal tract
  - Function
    - Execution of planned, voluntary, multijoint movements

- Programming the Cerebellum
  - Cerebellum- “brain inside”
    - Process of learning a new skill
    - New motor program created to ensure smooth movement
• Example of the baseball pitcher
- Walking: Ventromedial pathways
- Ready to pitch
  • cortex, ventromedial pathways
- Pitch signs and strategy
  • Sensory information engages parietal and prefrontal cortex and area 6

• Winds and throws
  • Increased basal ganglia activity (initiation)
  • SMA activity → M1 activation
  • Corticopontocerebellar pathways → Cerebellum
  • Cortical input to reticular formation → Release of anti-gravity muscles
  • Lateral pathway → engages motor neurons → action

The Somatosensory Cortex and Complex Movement
• Injury to secondary area results in apraxia (not action)
  • inability to make voluntary movements
  • Can describe but cannot carry them out
How Motor-Cortex Damage Affects Skilled Movements

Forced use permits retention of cortical representation