Ch 11. The Control of Action


Summarized by
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Parkinson’s Disease

- Cause: cell death in the substantia nigra
  - Substantia nigra
    - A brainstem nucleus that is part of the basal ganglia
    - Primary source of the neurotransmitter dopamine

- Not only disrupts the production and flexibility of voluntary movement but also can distort posture.
- Facial expression, including blinking, is frequently absent, giving the person the appearance of seeming to be frozen.
- Laboratory tests demonstrate that MPTP causes the death of dopaminergic cells.
  - MPTP: synthetic opioid, similar in structure to meperidine

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Contents

- Motor Structures
- Computational Issues in Motor Control
- Physiological Analysis of Motor Pathways
- Comparison of Motor Planning and Execution
- Functional Analysis of the Motor System and Movement Disorders

Motor Structures

- Muscles, Motor Neurons, and the Spinal Cord
- Subcortical Motor Structures
- Cortical Regions Involved in Motor Control
- The Organization of Motor Areas
Motor Structure

- Muscles are activated by the alpha motor neurons
  - The input from the alpha motor neurons causes the muscle fibers to contract.
  - Activation of triceps: extension of the elbow
  - Activation of biceps: flexion of the elbow
- Process of the stretch reflex
  - Raps your knee, the quadriceps is extended.
  - The sensory signal is transmitted through the dorsal root of the spinal cord and directly activates an alpha motor neuron to contract the quadriceps.
- In this manner, the stretch reflex helps to maintain the stability of the limbs following unexpected perturbations.

Subcortical Motor Structures (1/2)

- Pyramidal tract, extrapyramidal tract
Subcortical Motor Structures (2/2)

- Basal ganglia

![Basal ganglia diagram](http://bi.snu.ac.kr/)

Cortical Regions Involved in Motor Control

- Area 4
  - primary motor cortex
- Area 6
  - Medial surface: supplementary motor area (SMA)
  - Lateral surface: premotor cortex (PMC)
- Area 8 includes the frontal eye fields.

![Cortical regions diagram](http://bi.snu.ac.kr/)
Anatomical Organization of Motor Area (1/2)

- Motor cortex
  - organized, somatotopic representation of the body.
  - Electrical stimulus applied
    - To the medial wall of the precentral gyrus → foot movement
    - To the ventral lateral site → tongue movement
  - Size of effector reflects
    - The importance of that effector for movement
    - The level of control required for manipulating the effector.
    - Fingers span a large portion
  - Demonstration with TMS
    - As the center of the coil is moved downward, the effects of stimulation shift from movement of the upper arm to the wrist and then to individual fingers.

- Each cerebral hemisphere is devoted to controlling on the opposite side of the body.
  - Exception – Cerebellum

Anatomical Organization of Motor Area (2/2)

- Relation between motor areas
  - Hierarchy: multiple levels of control

- Motor control is a distributed process.
Peripheral Control of Movement and the Role of Feedback

- Neurons in the spinal cord can generate motor commands without the inputs from the brain
Peripheral Control of Movement and the Role of Feedback (2/3)

- Sensory signals are not essential for movements.
- If the dorsal root on one side of the body is sectioned, the animal does not use the limb.
- If the dorsal root on both sides are sectioned, the animal uses the limb.

Peripheral Control of Movement and the Role of Feedback (3/3)

- Patients with severe sensory deficits can still make complicated movements (patient with severe neuropathy).
- Movements are made in the dark. (time-lapse photography)
- Despite the absence of proprioceptive, kinesthetic, and visual feedback, the shapes are readily identified. – circle, a figure eight, and a square.
The Representation of Movement Plans (1/3)

- Location hypothesis (endpoint control of movement):
  - Distance-based hypothesis
- There is a cortical representation of motor plan in terms of the pointing movement.
- This central representation is based primarily on the end point of the movement.

The Representation of Movement Plans (2/3)

- Two Models of motor control
  - The hierarchical model
    - Goals are specified initially as target locations.
    - A translation process is then required to move limb to the goal.
  - Independent control model
    - Location and trajectory planning provide two different representations for determining muscle activity.
The Representation of Movement Plans (3/3)

- Dissociation of location and distance planning
  - The effect of illusion (by background motion) was obvious in the distance condition
  - The effect was minimal in the location condition
- The illusion produced differential effects in the two conditions indicates that the movements were guided by different representations
- Location planning
  - Represents a more ancient and primitive system
  - Specify the goal, or target location of an action
  - Produce movements that reach a final target location
  - Without much flexibility
- Distance planning
  - Specify the exact form with which an action will be achieved
  - Provide flexibility
  - Need additional costs of planning

Hierarchical Representation of Action Sequences (1/2)

- Skilled or sequential movements are guided by hierarchical representations
  - Organize the movement elements into integrated chunks. (relevant to capacity limits in memory)
  - Ex) Playing the piano, swinging the racquet.

- 1) Conceptual levels: corresponds to a representation of the goal of action
- 2) Response system level or lexical level
- 3) Motor implementation level
Hierarchical Representation of Action Sequences (2/2)

- The high-level representation is independent of any particular muscle group
  - There is a degree of similarity in the productions despite the vast differences in practice writing with these five body parts

Physiological Analysis of Motor Pathways

- The Neural Representation of Movement
The Neural Representation of Movement
(1/2)

- Directional tuning of motor cells
  - Population Vector: the summed activity over all of the cells
    - Each neuron’s contribution to a particular movement can be plotted as a vector
    - The direction of the vector is always plotted as the neuron’s preferred direction, and the length corresponds to its firing rate for the target direction.
  - In the motor cortex, the population vector shifts in the direction of the upcoming movement before the movement is produced.
  - This indicates that the cells help to plan the movement rather than simply reflect changes during a movement.

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Goal-Based Representation in Motor Structures (1/2)

- How important the final location
  - Monkeys were trained to make a two-step movement
- Result of population vector:
  - final component $\rightarrow$ gradually $\rightarrow$ first component
  - The initial shift was to the second component
- The motor plan unfolded in the reverse order of the actual movements – the initial representation was based on the final location

Goal-Based Representation in Motor Structures (2/2)

- Goal-based action depends on synthesizing sensory and motor information.
- Many cells in brain represent sensory and motor information, such as in the parietal cortex, frontal cortex, basal ganglia, cerebellum, and superior colliculus
- In this experiment, activity in a neuron in the basal ganglia dynamically shifts as a function of hand position – useful for coordinating visually guided movements
Comparison of Motor Planning and Execution

- Internal Versus External Guidance of Movement
- Shift in Cortical Control with Learning

Areas of activation during a variety of motor tasks
- Measuring regional cerebral blood flow (rCBF).
- Changing during simple movements are limited to primary motor and sensory areas in the contralateral hemisphere.
- During performing sequential movements, blood flow increases occur in premotor and sensory areas in the contralateral hemisphere and in supplementary motor area (SMA) and the inferior prefrontal regions in both hemispheres.
- During the imagery condition, blood flow increases were restricted to the supplementary motor area.
Comparison of Motor Planning and Execution (2/3)

- Internal versus external guidance of movement
  - The external loop (including the cerebellum, parietal lobe and lateral premotor cortex (PMC)) dominates during visual guided movements.
  - The internal loop (including the basal ganglia and supplementary motor area (SMA)) dominate during self-guided, well-learned movements.

Comparison of Motor Planning and Execution (3/3)

- Sequential button press
  - To a series of illuminated targets
    - SMA neuron was most active during the internal condition
  - From memory
    - PMC neuron was most active during the external condition
Shift in Cortical Control with Learning

- Shift in metabolic activity (PET scans)
  - Perform well-learned movement sequence (Old)
    - Supplementary motor area (SMA)
    - Hippocampus
  - Perform during the course of learning of a movement sequence (New)
    - Lateral premotor
    - Prefrontal areas

Functional Analysis of the Motor System and Movement Disorders

- Cortical Areas
- Subcortical Areas: The Cerebellum and Basal Ganglia
Hemiplegia

- Lesions to motor cortex result in hemiplegia, the loss of voluntary movements on the contralateral side of the body.
- Causes: a hemorrhage in the middle cerebral artery which leads to damages in the motor cortex.
- Symptom: muscle spasticity.
- Recovery: minimal.
- The hemiplegic patient cannot easily generate an action based on internal goals and desires.

Apraxia (1/2)

- A loss of motor skill
- When they are asked to pantomime actions

May not recognize skilled movement.
Perception test: choose appropriate action
Apraxia (2/2)

- Apraxia: no action
  - Know how the action should be completed but could not execute it.
- Diagnosis of apraxia
  - Has a coordination problem that cannot be linked to a deficit in controlling the muscles themselves.
  - Almost all apraxia patients have some aphasia (left hemisphere)
- The left parietal lobe may contain representations of skilled movements (skilled movements)
  - When damaged, the patient has difficulty generating these actions or recognizing them when produced by others
  - Damage to these areas also can produce apraxia

The Cortex and Selection of Movement: Translating a Goal into Movement (1/3)

- Take a swig from his coffee cup
  - Response selection involves a competitive process between potential responses
  - Reach with either left or right hand
  - Either from the current position or by rotating the trunk
- Cortical selection hypothesis for the selection of movement:
  - Motor planning involves many neural regions.
  - The supplementary motor area play a major role in selecting a movement.
  - The motor cortex performs the selected movement plan.
Physiological correlates of response competition
- Compatible condition: move the handle to the location of the stimulus
- Incompatible condition: move the handle to the opposite direction of the stimulus
- Recorded region
  - Population vectors were recorded in the lateral premotor cortex

The planned movement activates both hemispheres
- Activation eventually becomes lateralized over the contralateral motor cortex
- Activation of the supplementary motor area in one hemisphere
  - Promotes the selection of a movement on the contralateral side
  - Inhibits a similar movement on the ipsilateral side.
- Lesions of the SMA
  - Have tendency to produce mirror movements (ipsilateral hand)
Cerebellum (1/3)

- Lesions of the cerebellum disrupt coordination in a variety of ways

- Three divisions of the cerebellum
  - Spinocerebellum
  - Neocerebellum
  - Vestibulocerebellum

Cerebellum (2/3)

- Vestibulocerebellum
  - The vestibulocerebellum is innervated by the brainstem vestibular nuclei, and output is projected back to the same region.
  - The vestibular system is essential for controlling balance and coordinating eye movements with body movements. VOR = vestibular-ocular reflex.
  - Lesions of this area causes problems for body balance and stability.

- Spinocerebellum
  - The spinocerebellum receives extensive sensory information from the periphery via the spinal cord.
  - The output from the spinocerebellum originates in the medial cerebellar nuclei and innervates the spinal cord and nuclei of the extrapyramidal system.
  - Lesions of the spinocerebellum causes problems for the smooth control of movement.
  - The cells in this area is very sensitive to the effects of alcohol. Police use testing cerebellar function to find drunk drivers.
  - Some of the fibers project to the motor cortex via the thalamus.
Cerebellum (3/3)

- Neocerebellum
  - Neocerebellum is innervated by descending fibers from the cerebral cortex originating from many regions in the parietal and frontal lobes.
  - The output from the neocerebellum originates in the lateral deep nucleus, the dentate.
  - From there, some fibers terminate on nuclei of the extrapyramidal system, others ascend to the cortex via the thalamus.
  - The function of neocerebellum is to assist in the control of voluntary movements.
  - Lesions of the neocerebellum causes that the movements are clumsy and the initiation of the movement is extended.

Basal Ganglia (1/5)

- Basal ganglia
  - The other major subcortical motor structure
  - Composed of five nuclei: caudate, putamen, globus pallidus, subthalamic nuclei, and substantia nigra
  - Lesions of the basal ganglia interfere with coordinated movement
Basal Ganglia (2/5)

- Acts as a gatekeeper of cortical activity and plays a critical role in movement initiation.
- Ideally designed to function as a winner-take-all system, a method for committing to one action from among the various alternatives.

Basal Ganglia (3/5)

- Two successive inhibitory links
  - Globus pallidus and striatum
  - Disinhibit the selected response
  - The most efficient way to make a selected pattern stand out from the background
Basal Ganglia (4/5) – Disorders

- Huntington’s disease
  - Atrophy is most prominent in the basal ganglia, and the cell death rate is as high as 90% in the striatum
- Parkinson’s disease
  - A loss of dopaminergic fibers originating in the substantia nigra and projecting to the striatum
  - The neurons in these areas significantly decreased, which in turn causes the low secretion of dopamine
Basal Ganglia (5/5) – Disorders

- Differential neurochemical alterations in Huntington’s and Parkinson’s diseases
  - Huntington’s disease: the inhibitory projection along the indirect pathway from striatum to the external segment of the globus pallidus is reduced.
  - Parkinson’s disease: reduces the inhibitory activity along the direct pathway.

The Diagram for the Summary

![Diagram](http://bi.snu.ac.kr/)
Key Terms

- Alpha motor neurons
- Basal ganglia
- Cerebellum
- Deafferented
- Endpoint control
- Hemiplegia
- Hypermetria
- Ideomotor apraxia
- Population vector
- Primary motor cortex
- Supplementary motor area
- Apraxia
- Bradykinesia
- Cortico-spinal tract
- Effector
- Extrapyramidal tracts
- Huntington’s disease
- Ideational apraxia
- Parkinson’s disease
- Premotor cortex
- Substantia nigra

Thought Questions

- Motor control, when viewed both from a functional perspective and from a neuroanatomical/neurophysiological perspective, involves a hierarchical organization. Outline this hierarchy, starting with the most basic or primitive aspects of motor behavior and progressing to the highest level or most sophisticated aspects of motor behavior.
- What is the difference between the pyramidal and extrapyramidal motor pathways? What type of movement disorder would you expect to see if the pyramidal tract is damaged? How would extrapyramidal damage differ?
- What types of movements are possible without feedback? How might feedback be used by the motor system, both for on-line control and for learning?
- Explain the concept of the population vector. How could it be used to control a prosthetic (artificial) limb?
- Why do people with Parkinson’s disease have difficulty moving? Provide an explanation based on the physiological properties of the basal ganglia. Why does dopamine replacement therapy improve their condition?
Extra Figures

Adjust for perceptual judgments

Target

D2

E

D1

O

Signal from primary motor cortex

Water bottle

Robot arm with water

Two position robot arm activation switch

Lever

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Possible mental operations/computations

1. Select
2. Sequence
3. Force
4. Timing

Example: playing piano

- Match fingers to keys and notes.
- Group notes into a phrase.
- Strike accented notes with greater force.
- Establish rhythm.

Diagram: Mirror symmetric and Non-symmetric states of corpus callosum in intact and callosotomy patients.
(a) Motor shifting experiment

Learn sequence A:
Index-Ring-Middle (I-R-M)
Learn sequence B:
Index-Middle-Ring (I-M-R)

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<th>Condition</th>
<th>Stimulus</th>
<th>Response sequence</th>
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<td>No shift</td>
<td>AA</td>
<td>I-R-M I-R-M</td>
</tr>
<tr>
<td>Shift</td>
<td>BA</td>
<td>I-M-R I-M-R</td>
</tr>
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(b) Cognitive shifting experiment

Possible stimuli:
- Red Square
- Green Triangle
- Color

Relevant dimension

<table>
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<th>Condition</th>
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<th>Trial 2</th>
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<td>Shape</td>
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<tr>
<td>Shift</td>
<td>Color</td>
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RT (ms) for Trial 2

- No shift
- Shift

Group
- Controls
- Parkinson's