Objectives

- Describe the roles of the cerebellum.
- Identify gross anatomic structures of the cerebellum.
- Discuss the functions of the vestibulocerebellum, spinocerebellum, and cerebrocerebellum.
- List the nuclei that constitute the basal ganglia. List the names that include two nuclei.
- List the functions of the three cortico-basal ganglia-thalamic nonmotor loops.
- List the function of the oculomotor cortico-basal ganglia-thalamic loop.
- List the functions of and the structures within the cortico-basal ganglia-thalamic motor loop.
- Describe the hyperdirect, Go, and No-Go pathways that determine the basal ganglia effect on movement.
- Define *feedforward* and *feedback*, and use them to describe a functional task.
- Describe the three classifications of movement.
- Compare the inputs and outputs of the basal ganglia with the inputs and outputs of the cerebellum as they contribute to normal movement.
Introduction to the Cerebellum

- Cerebellum adjusts posture; coordinates movements.
- To achieve smooth movements, the cerebellum integrates information from the frontal lobes about intended movements with sensory information.
- No direct connections between cerebellum and motor neurons
- Cerebellum literally means “little brain.”
- Cerebellum lies inferior to the occipital lobe.
- Each of two cerebellar hemispheres is attached to posterior brainstem by three large bundles of axons.
  - Superior cerebellar peduncles
  - Middle cerebellar peduncles
  - Inferior cerebellar peduncles

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(Lundy-Ekman, 2018, p. 291)  
Image: (Jarvis, 2016, p. 633)
Cerebellar Lobes & Peduncles

- Cerebellum has three lobes in each hemisphere.
  - Anterior
  - Posterior
  - Flocculonodular
- Vertically, the cerebellum can be divided into three functional regions.
  - Midline vermis
  - Paravermis
  - Lateral hemisphere
- Axons connecting the cerebellum with the brainstem form three cerebellar peduncles on each side of the brainstem.
- Superior cerebellar peduncle connects to the midbrain, middle connects to the pons, and inferior cerebellar peduncle connects to the medulla.
• Cerebellum has specialized regions for controlling each of these aspects of movement.
  1. Vestibulocerebellum
  2. Spinocerebellum
  3. Cerebrocerebellum
Functional Regions of the Cerebellum cont.

1. Vestibulocerebellum

- Located in the flocculonodular lobe
- Receives input from the ipsilateral vestibular apparatus and ipsilateral vestibular nuclei in the brainstem
- Vestibular and visual afferent information enters the cerebellum and synapses in the flocculonodular cortex.
Functional Regions of the Cerebellum cont.

Spinocerebellum

- Functional name for the vermis and the paravermal region because of the extensive connections with the spinal cord
- Receives information about movement commands from the cortex, about activity levels of spinal cord neurons, and about movements or postural adjustments from proprioceptors
- Two spinocerebellar pathways deliver high-fidelity information from peripheral receptors in muscles, tendons, and joints to the cerebellum.
Spinocerebellar Pathways and Tracts

- Information in the spinal cord destined for the cerebellum travels in spinocerebellar tracts.
- Two spinocerebellar pathways deliver high-fidelity information from peripheral receptors in muscles, tendons, and joints to the cerebellum.
High-Fidelity Pathways

• Two pathways relay high-fidelity, somatotopically arranged information to the cerebellar cortex:
  – Posterior spinocerebellar pathway - Transmits proprioceptive information from the lower limb and the lower trunk
  – Cuneocerebellar pathway - Begins with primary afferents from proprioceptors in the neck, upper limb, and upper half of the trunk

(Lundy-Ekman, 2018, p. 294)
Internal Feedback Tracts

- The two single-neuron internal feedback tracts monitor the activity of spinal interneurons and of descending motor signals from the cerebral cortex and brainstem.
  - Anterior spinocerebellar tracts - Transmits information from the thoracolumbar gray matter
  - Rostrospinocerebellar tracts - Transmits information from the cervical spinal cord and T1 to the ipsilateral cerebellum and entered the cerebellum via the inferior and superior cerebellar peduncles

(Lundy-Ekman, 2018, p. 294)
Functional Regions of the Cerebellum cont.

3. Cerebrocerebellum

- Named for its extensive, indirect connections with almost the entire cerebral cortex
- Dentate nucleus is involved in motor planning.
- Functions include:
  - coordination of voluntary movements via influence on corticospinal, corticobrainstem, and rubrospinal tracts.
  - planning of movements.
  - timing.
  - cognitive functions
- Cerebellum makes adjustments before excitation of the rubrospinal and lateral corticospinal tracts.

(Lundy-Ekman, 2018, p. 297)
Signs of Cerebellar Dysfunction

- Signs of cerebellar motor dysfunction involve abnormal motor execution that does not change with or without use of vision.
- **Ataxia**: Movement disorder common to all lesions of the cerebellum
- Lesions involving the **vestibulocerebellum** cause **nystagmus**, unsteadiness, and difficulty maintaining sitting and standing balance.

- **Spinocerebellar** lesions result in limb ataxia, with the following manifestations:
  - **Dysdiadochokinesia**
  - **Dysmetria**
  - **Action tremor**
Differentiating Cerebellar From Somatosensory Ataxia

- Not all ataxia is caused by cerebellar lesions.
- To differentiate between somatosensory and cerebellar ataxia, movement coordination should be compared with eyes open and eyes closed.
- Cerebellar lesions cause ataxia regardless of the use of vision.
Introduction to Basal Ganglia

- The basal ganglia are involved in decision making, judgment, prioritizing information, emotional processing and responses, learning, eye movements and spatial attention, and motor output.
- Both the basal ganglia and the cerebellum adjust activity in the descending motor tracts (MTs), despite lack of direct connections with motor neurons (MNs).
- The basal ganglia and the cerebellum influence movement via different pathways through the thalamus to motor areas of the cerebral cortex and by connections with MTs.
- The basal ganglia predict the effects of various actions and then select and execute action plans largely by inhibiting competing motor actions that would otherwise interfere with the desired movement.

Image: (Jarvis, 2016, p. 634)
Anatomic Orientation to the Basal Ganglia

• Predict the effects of various actions, then make and execute action plans.
• Include the following nuclei:
  – Caudate: Located in the cerebrum
  – Putamen: Located in the cerebrum
  – Globus pallidus: Located in the cerebrum
  – Subththalamic nucleus (STN): Located within the diencephalon
  – Substantia nigra: Located within the midbrain
• Based on anatomic proximity, the cerebral basal ganglia have joint names
  – Lentiform nucleus: globus pallidus + putamen
  – Striatum: caudate + putamen
  – Ventral striatum: Junction of caudate and putamen
  – Nucleus accumbens: Part of ventral striatum
Basal Ganglia Motor Circuitry

- Basal ganglia involvement in non motor functions occurs through three cortico-basal ganglia-thalamic circuits
  1. Goal-directed behaviour loop
  2. Social behaviour loop
  3. Emotion loop
- Loops contribute to the prediction of future events, selecting desired behaviors, preventing undesired behaviors, motor learning, shifting attention, and spatial working memory.
Behavior Loops

1. Goal-directed behaviours loop
   • Head of the caudate is part of the decision-making loop that participates in goal-directed behavior.
   • Evaluates information for making perceptual decisions, planning, and choosing actions in context.
   • Active in learning, changing its activity before the cortex when reward contingencies are reversed.
   • Is not involved in controlling movements.

2. Social behaviour loops
   • Head of the caudate is part of the loop that recognizes social cues, regulates self-control, and parses out relevant from irrelevant information.

3. Emotional behaviour loops
   • Ventral striatum participates in emotions and motivation; acts as a link between emotion, cognitive, and motor systems.
   • Integrates emotions with roles of other loops.
   • Partially responsible for the perception and experiences of emotions.
   • Essential function is seeking rewards.

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(Lundy-Ekman, 2018, p. 303)
Basal Ganglia Motor Circuitry

- Motor loops functions of the basal ganglia
- Output of the basal ganglia motor circuit regulates muscle contraction, muscle force, multijoint movements, and the sequence of movements.
- Includes the cerebral cortex motor areas, putamen, STN, GPi, and the motor areas of the thalamus
Oculomotor Loop

- Body of caudate is part of an oculomotor loop that makes decisions about spatial attention and eye movements.
  - Specifically determining whether to use fast eye movements to direct attention toward an object
  - *Saccade*: Rapid movement of the eyes
  - *Antisaccades*: Result of more complex interactions and require inhibition of prosaccade reflex

(Lundy-Ekman, 2018, p. 305)
Motor Loop

- Output of cortico-basal ganglia-thalamic motor loop
- Regulates muscle contraction, muscle force, multijoint movements, and sequencing of movements
- Includes cerebral cortex motor areas, the substantia nigra compacta, putamen, globus pallidus externus (GPe), STN, GPi, and motor areas of the thalamus
<table>
<thead>
<tr>
<th>Cortico-basal ganglia-thalamic loops</th>
<th>Cerebral cortex</th>
<th>Basal ganglia</th>
<th>Thalamic nuclei</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal-directed behavior loop</td>
<td>Lateral prefrontal cortex</td>
<td>Head of caudate, globus pallidus</td>
<td>Ventral anterior</td>
</tr>
<tr>
<td>Social behavior loop</td>
<td>Ventral prefrontal cortex</td>
<td>Head of caudate, substantia nigra reticularis</td>
<td>Mediodorsal</td>
</tr>
<tr>
<td>Emotion loop</td>
<td>Medial prefrontal cortex</td>
<td>Ventral striatum, ventral pallidum</td>
<td></td>
</tr>
</tbody>
</table>

| Motor loop                          | Motor and premotor cortex | Putamen, globus pallidus | Ventral lateral |
| Oculomotor loop                     | Frontal and supplementary eye fields | Caudate body and substantia nigra reticularis | Ventral anterior |
Hyperdirect, Go, and No-Go Pathways

These three pathways process signals within the cortico-basal ganglia-thalamic loop

1. Hyperdirect
   • Powerful inhibition of the motor thalamus.
   • Conveys powerful excitation from the cerebral cortex directly to the STN, the STN excites the GPi, and the GPi inhibits the motor thalamus

2. Go
   • Disinhibits the motor thalamus.
   • The sequence of activity when Go pathway is activated: putamin inhibits the GPi, the inhibited GPi provides less inhibition to the motor thalamus, and then the motor thalamus signals motor areas in the cerebral cortex to activate specific corticospinal neurons

3. No – Go
   • Also begins in putamen, in different cells than the Go pathway
   • The end result of No-Go pathway activity is suppression of unwanted movements.

(Lundy-Ekman, 2018, pp. 305-7)
Basal Ganglia Motor Control

- Although basal ganglia have profound effects on movement, they have no direct output to MNs.
- Functionally, motor loop regulates three activities via three pathways
  - Voluntary muscle activity
  - Postural and girdle muscle activity
  - Walking

Image: (Lundy Ekman 2018, p.307)
Effect of Dopamine on the Go and the No-Go Pathways

- Motor loop is dependent on DA supplied by the substantia nigra compacta.
- DA binding to D₁ receptors excites the inhibitory neurons in the Go pathway.
- DA binding to D₂ receptors inhibits the neurons from putamen to the GPe; disinhibits the STN and facilitates the GPi.

Basal Ganglia Regulation

- Basal ganglia tonically inhibit the motor thalamus, PPN, and MLR.
- In normal neuromotor system, the tonic inhibition is selectively decreased or increased depending upon the desired movement.

(Lundy-Ekman, 2018, p. 309)
Feedforward and Feedback

- In normal actions, feedforward and feedback interact to create and adjust movement.
- Feedforward consists of anticipatory motor impulses that prepare the body for movement.
- Feedback is information about the state of the system.
- Three types of movement include:
  - Postural: Is controlled by brainstem mechanisms
  - Ambulatory: Is controlled by brainstem and spinal regions
  - Reaching/grasping: Is controlled by the cerebral cortex
- All regions of the nervous system contribute to each type of movement.
Postural Control

• Provides orientation and balance
  – Orientation is the adjustment of the body and head to vertical.
  – Balance is the ability to maintain the center of mass relative to the base of support.

• Is achieved by central commands to the MNs; the central output is adjusted to the environmental context by sensory input

• To orient to the world, three senses are used
  – Somatosensation: Provides information about weight bearing and the relative positions of body parts
  – Vision: Provides information about movement and cues for judging upright
  – Vestibular: Informs a person about head position relative to gravity and about head movement
Ambulation

- All regions of the nervous system are required for normal human ambulation.
- Cerebral cortex provides goal orientation and control of ankle movements.
- Basal ganglia govern generation of force.
- Cerebellum provides timing, coordination, and error correction.
- Sensory information is used to adapt motor output appropriately.
- During normal gait initiation, the swing limb first pushes downward and then backward against the support surface.
- Pattern of force results in the center of mass being moved forward and onto the stance leg in preparation for foot-off and increases the magnitude of the subsequent movement.

(Lundy-Ekman, 2018, pp. 320)
Reaching and Grasping

- Vision and somatosensation are essential for reaching and grasping.
- Vision provides information for locating an object in space and assessing its shape and size.
- Feedforward is the primary role of visual information; if the movement is inaccurate, vision also guides corrections.
- Action stream flows from the visual cortex to the posterior parietal cortex.
- Grasping is coordinated with activity of the eyes, head, proximal upper limb, and trunk; orientation and postural preparation are integral to the movement.
- When the object is contacted, grip force adjusts quickly, indicating feedforward control.
- After the object is grasped, somatosensory information corrects any error in grip force.
Introduction to Cerebellar Testing

MSTN121 - Neurophysiology
Session 8

Department of Myotherapy
# Cerebellum Examination

<table>
<thead>
<tr>
<th>Name of Test</th>
<th>Test</th>
<th>Abnormal Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Romberg Test</strong></td>
<td>Ask the client to stand up with feet together and arms at side. Once in a stable position, ask the client to close their eyes and to hold the position. Wait for approximately 20 seconds. Stand close to the client to ‘catch’ them in case they fall. Maintaining posture and balance even with visual orientation blocked in the normal response. Slight swaying may occur.</td>
<td>Swaying, fall, widening base of feet to avoid falling, opening their eyes or moving their arms to maintain balance is a railed Romberg Test. A positive Romberg Test is a loss of balance with the eyes closed. Occurs with cerebellar ataxia (e.g. Multiple Sclerosis, alcohol intoxication), loss of proprioception and/or loss of vestibular function.</td>
</tr>
</tbody>
</table>

*(Jarvis, 2016, p. 650)*

(Image: Jarvis, 2016, p. 650)
## Cerebellum Examination

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| **2. Finger to Finger Test** | With the client’s eyes open, ask them to use their index finger to touch your finger and then his or her own nose. After a few times, move the location of your finger. The movement should be smooth and accurate. | Lack of coordination.  
  - Dysmetria = is clumsy movement with overshooting the mark and occurs with cerebellar disorders or acute alcohol intoxication.  
  - Past pointing = constant deviation to one side  
  - Intention tremor = occurs when reaching to a visually directed object. |
## Cerebellum Examination

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<tr>
<td><strong>3. Finger to Nose Test</strong></td>
<td>Ask the client to close their eyes and stretch out their arms in front of them. Ask him or her to touch the tip of his nose with each index finger, alternating hands and increasing speed. Normally this is done with accurate and smooth movement.</td>
<td>Missing nose. Worsening of coordination when their eyes are closed occurs with cerebellar disease or alcohol intoxication.</td>
</tr>
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<tr>
<td>4. Heel to Shin Test</td>
<td>This tests lower extremity coordination. Client is in a supine position, and we ask them to place their heel on their opposite knee and run it down their shin from the knee to ankle. A normal response is moving the heel in a straight line down the shin.</td>
<td>Lack of coordination and/or heel falls off shin; occurs with cerebellar disease.</td>
</tr>
</tbody>
</table>

*(Image: Jarvis, 2016, p. 649)*
## Cerebellum Examination

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</thead>
<tbody>
<tr>
<td>5. Rapid Alternating Movements (RAM)</td>
<td>With the client in a seated position, ask them to pat the knees with both hands, lift them up, turn hands over and pat the knees with the backs of their hands. Then ask them to do this faster. This is done with equal turning and a quick, rhythmic pace.</td>
<td>Lack of coordination. Slow, clumsy and sloppy responses are termed dysdiadochokinesia and occurs with cerebellar disease.</td>
</tr>
</tbody>
</table>

(Jarvis, 2016, p. 648)
## Cerebellum Examination

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</thead>
<tbody>
<tr>
<td>6. Nystagmus of the eye</td>
<td>Nystagmus is a rhythmic movement of the eye with an abnormal slow drifting away from a fixation and rapid return.</td>
<td>Drifting of eyes with horizontal gaze. Cerebellar nystagmus is greater when the eyes are deviated towards the side of the lesion.</td>
</tr>
<tr>
<td></td>
<td>Ask the client to look to both sides.</td>
<td></td>
</tr>
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## Cerebellum Examination

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<tr>
<td>7. Rebound Phenomenon</td>
<td>Have the client place their hand in a bicep curl position. Start to resist elbow flexion of the client. Without warning, slip your hand out of their grasp. Normal response: the antagonists muscles will contract and stop their arm from moving in the desired direction. <strong>Be careful to protect the client from the movement which may cause them to strike themselves if cerebellar disease is predicted.</strong></td>
<td>A positive sign is seen when an exaggerated rebound occurs with movement in the opposite direction. In cerebellar disease the response is completely absent causing the limb to move in the desired direction.</td>
</tr>
</tbody>
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## Vestibular Examination

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</tr>
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<tbody>
<tr>
<td><strong>8. Head Impulse Test</strong></td>
<td>Ask the client to maintain gaze at your nose whilst seated.</td>
<td>A positive test is when the client cannot maintain their gaze of nystagmus is noted.</td>
</tr>
<tr>
<td></td>
<td>While they are doing so you rapidly turn the clients neck (holding their head) 20 degrees in both directions from neutral.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>*ensure no extension or flexion occurs with the rotation.</td>
<td></td>
</tr>
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## Vestibular Examination

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</thead>
<tbody>
<tr>
<td>9. Dix-Hallpike Test</td>
<td>Start with the client seated with legs extended on the table. Turn their head 45 degrees and observe their eyes for 30 seconds. Observe their eyes for 30 seconds in this position. Warn your client you are going to drop them down (supine position) (see image). While holding the clients head, drop them backwards into the supine position with their head extended off the table (20 degrees). If nystagmus occurs up to 1 minute later this indicates Benign Paroxysmal Positional Vertigo (BPPV).</td>
<td>Nystagmus occurring up to 1 minute later this indicates Benign Paroxysmal Positional Vertigo (BPPV).</td>
</tr>
</tbody>
</table>
Revision Questions

1. Describe the roles of the cerebellum.
2. Discuss the functions of the vestibulocerebellum, spinocerebellum, and cerebrocerebellum.
3. Identify signs associated with cerebellar pathology.
4. Explain how to distinguish between impairments due to cerebellar lesions and lesions involving the somatosensory system.
5. List the functions of the three cortico-basal ganglia-thalamic nonmotor loops.
6. List the function of the oculomotor cortico-basal ganglia-thalamic loop.
7. Describe the hyperdirect, Go, and No-Go pathways that determine the basal ganglia effect on movement.
8. Define dystonia and describe cervical dystonia and focal hand dystonia.
9. Define feedforward and feedback, and use them to describe a functional task.
10. Compare the inputs and outputs of the basal ganglia with the inputs and outputs of the cerebellum as they contribute to normal movement.
References

Image references

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