NEUR 1520 Neuroscience Study Guide for Exam 2: Book 5.3: Movement

Source: The Mind's Machine, Chapter 5 (no Chapter 5 lecture slides are posted yet). Nothing else.
Each heading is one book learning objective. [MM p148] = book page 148.
(teal italics) = plain meaning of the word before it. ⚠ **Do not mix up = a look-alike pair to keep apart.** **Amber dotted words** = names printed on the figure beside them.

Contents

5.3.1 Discuss the importance of motor planning and sensory feedback in controlling behavior 1
5.3.2 Trace the pathways by which the brain sends commands to individual muscles 2
5.3.3 Distinguish between the two main types of sensory feedback from muscles to the nervous system 6
5.3.4 Discuss the interaction of various cortical and subcortical brain regions in regulating behavior 8
5.3.5 Describe the behavioral symptoms and underlying pathology of two major motor disorders 10

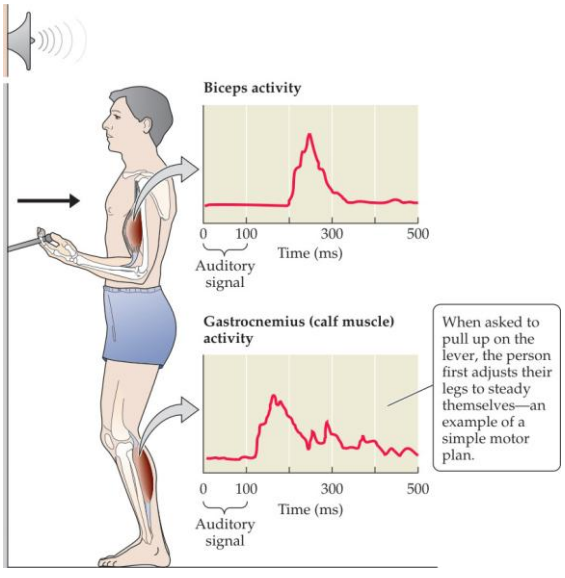
Click a line to jump to it. The PDF side panel (bookmarks) has the same parts.

5.3.1 Discuss the importance of motor planning and sensory feedback in controlling behavior

⚠ **Do not mix up: Acts are NOT chains of reflexes: a motor plan is set BEFORE the act begins.** [MM p161]

All behavior involves movements: muscle contractions are our sole means of interacting with the world. [MM p161]
Movement: a single relocation of a body part, usually from a brief muscle contraction. [MM p161]
Reflex: a simple, highly stereotyped, unlearned response to a particular stimulus. [MM p161]
Reflex example: an eye blink in response to a puff of air. [MM p161]
Act: complex behavior, as distinct from a simple movement (getting dressed, walking, speaking). [MM p161]
Old idea: reflexes are the basic units; acts are reflexes chained, each sensation triggering the next. [MM p161]
Flaw: units fit a larger plan and are not always produced in the same order. [MM p161]
Motor plan (also **motor program**): a set of muscle commands established BEFORE the act occurs. [MM p161]
Feedback from movements informs and fine-tunes the motor program while it unfolds. [MM p161]
But the basic sequence of movements is planned ahead. [MM p161]
Motor plan examples range from skilled piano playing to simple escape behaviors of crayfish. [MM p161]

Electromyography (EMG) *(recording electrical activity of muscles)*: electrical recording of muscle activity. [MM p161]
EMG plus body positions lets researchers track the simple movements that make up an act. [MM p161]
EMG experiment: after an auditory signal, a person pulls up on a **lever**. [MM p161]
Calf muscle (**gastrocnemius**) fires BEFORE the **biceps**: legs steady the body before the arm pulls. [MM p161]
Adjusting the legs before moving the arm is an example of a simple **motor plan**. [MM p161, MM p162]
Motor plans resemble engineering: two goals, accuracy (minimize error) and speed (finish quickly). [MM p162]
Speed and accuracy trade-off: improving one goal usually costs the other, in machines and nervous systems. [MM p162]
Neuromuscular system: muscles plus brain mechanisms and nerves that prepare and execute motor plans. [MM p162]
The neuromuscular system also gets sensory feedback for use in error correction. [MM p162]



Muscle activity recorded while a person pulls a lever: calf before biceps [MM p161]
On the figure: gastrocnemius · biceps · calf muscle · lever · motor plan

The six levels of the motor control hierarchy, as the book numbers them: [MM p162]

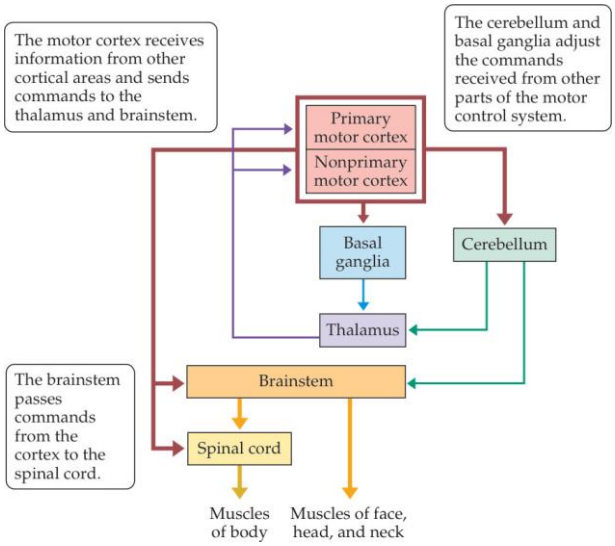
> **1. Skeletal system** and attached muscles: determine which movements are possible. [MM p162]
>
> **2. Spinal cord**: controls skeletal muscles on brain commands, or directly from sensory input in reflexes. [MM p162]
>
> **3. Brainstem**: integrates motor commands from higher brain levels and sends them to the spinal cord. [MM p162]

Brainstem also relays body sensory information from spinal cord to forebrain. [MM p162]

> **4. Primary motor cortex**: initiates some of the main commands for action. [MM p162]
>
> **5. Nonprimary motor cortex** *(motor areas next to M1)*: extra commands, via M1 and directly to lower levels. [MM p162]

Very top of the hierarchy: **prefrontal cortex**, crucial for formulating behavioral plans. [MM p162]

> **6. Cerebellum** and **basal ganglia**, via the **thalamus**: modulate other parts of the control system. [MM p162]



Hierarchy of movement control from cortex to muscles [MM p162]

On the figure: primary motor cortex · nonprimary motor cortex · basal ganglia · cerebellum · thalamus · brainstem · spinal cord

> Motor cortex gets information from other cortical areas; sends commands to thalamus and brainstem. [MM p162]
>
> Cerebellum and basal ganglia adjust commands received from other parts of the motor control system. [MM p162]
>
> Basal ganglia and cerebellum send output to the thalamus; the thalamus feeds the motor cortex. [MM p162]
>
> Brainstem passes commands from cortex to spinal cord. [MM p162]
>
> Spinal cord drives muscles of the body; brainstem drives muscles of face, head, neck. [MM p162]
>
> Visual Summary: hierarchy = skeleton and muscles, spinal cord, brainstem, M1, nonprimary cortex, cerebellum, basal ganglia. [MM p174]
>
> Review, reflex vs movement vs act: unlearned stereotyped response; single body part relocation; complex behavior. [MM p161, MM p162]
>
> Review, sensory feedback: informs and fine-tunes the motor plan and allows error correction. [MM p161, MM p162]
>
> Review, speed vs accuracy: improving one usually comes at a cost to the other. [MM p162]
>
> Review, motor plan: commands to muscles set up in the nervous system before the act. [MM p161]

Reflex vs movement vs act

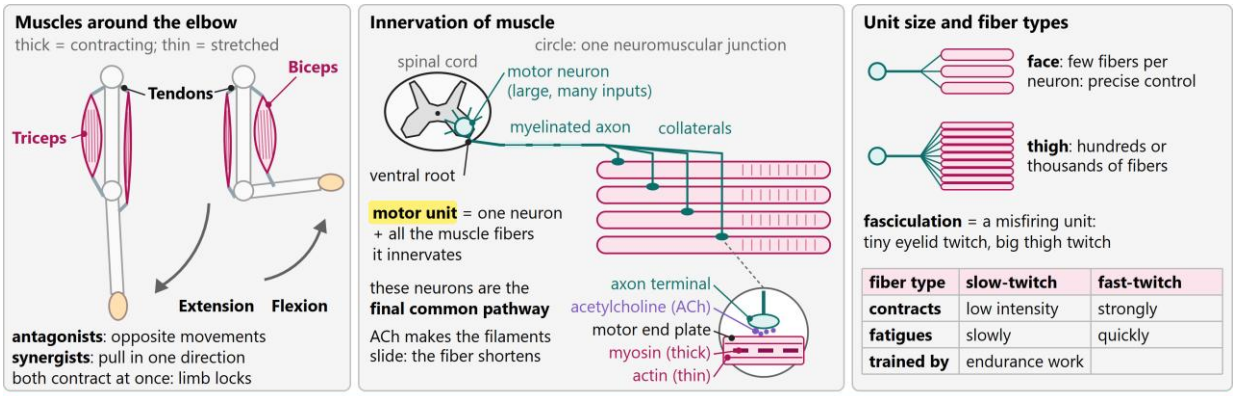
Term	What it is	Example
Reflex	Simple, unvarying, unlearned response to stimulus	Eye blink to puff of air
Movement	Single relocation of a body part	An arm movement or leg movement
Act	Complex behavior built from many movements	Dressing, walking, speaking a sentence

Table source: [MM p161]

5.3.2 Trace the pathways by which the brain sends commands to individual muscles

⚠ **Do not mix up: Pyramidal tracts CROSS in the medulla: the LEFT motor cortex controls the RIGHT body side.** [MM p167]

> Joints vary in planes of movement: universal joints (hip, shoulder) vs hinge joints (elbow, knee). [MM p162]
>
> Hinge joints move mostly in one direction. [MM p162]
>
> **Tendons** *(cords tying muscle to bone)* connect muscles to bones. [MM p162]



Muscles around the elbow, motor unit and neuromuscular junction, fiber types [MM p163]

On the figure: antagonist · synergist · tendons · triceps · biceps · motor unit · neuromuscular junction · fasciculation

Muscles around a joint are reciprocal: one group contracting stretches the other group. [MM p162]

Antagonist: a muscle that counteracts the effect of another muscle. [MM p162]

Synergist: a muscle that acts together with another muscle, moving a limb one direction. [MM p162]

Limb movement depends on degree and rate of contraction in some muscles, relaxation in others. [MM p162, MM p163]

Contracting opposing muscles at the same time locks a limb in position. [MM p163]

Muscles exert force **only** by contracting, so muscle attachments determine the resulting movement. [MM p163]

Elbow: **triceps** extends the arm; **biceps** flexes it; so they are antagonists. [MM p163]

Skeletal muscles move the skeleton; they are **striate muscle** *(striped looking muscle)*. [MM p163]

Stripes come from overlapping layers of contractile proteins **myosin** and **actin**. [MM p163]

Smooth muscle: in visceral organs and blood vessels; not generally involved in voluntary behavior. [MM p163]

Contraction: actin and myosin filaments slide past each other, overlap **increases**, the fiber shortens. [MM p163]

Most muscles mix two fiber types: slow-twitch and fast-twitch. [MM p163]

Endurance athletes enhance the slow-twitch properties of their muscles through training. [MM p163]

Motor neuron (also **motoneuron**): neuron that transmits neural messages to muscles (or glands). [MM p163]

Motor neurons of the spinal cord and brainstem make muscles contract. [MM p163]

Neuromuscular junction: where the motor neuron terminal meets its target muscle fiber. [MM p163]

The neuromuscular junction is where the nerve transmits its message to the muscle fiber. [MM p163]

A motor neuron action potential releases **acetylcholine (ACh)** at ALL of its axon terminals. [MM p163, MM p164]

ACh: neurotransmitter released by the autonomic nervous system, motor neurons, and neurons throughout the brain. [MM p163]

Muscle fibers respond to ACh with molecular events making actin and myosin contract. [MM p164]

Motor unit: one motor neuron plus all the muscle fibers it innervates. [MM p164]

Fasciculation *(small involuntary muscle twitch)*: a misfiring motor unit. [MM p164]

Example: eyelid "jumping nerves" when fatigued is a misfiring facial motor unit. [MM p164]

Spinal motor neurons have large cell bodies and very widespread dendritic fields. [MM p164]

Why: they integrate sensory inputs plus descending brain signals through thousands of synapses. [MM p164]

Virtually all motor neuron axons are myelinated, so action potentials reach muscles quickly. [MM p164]

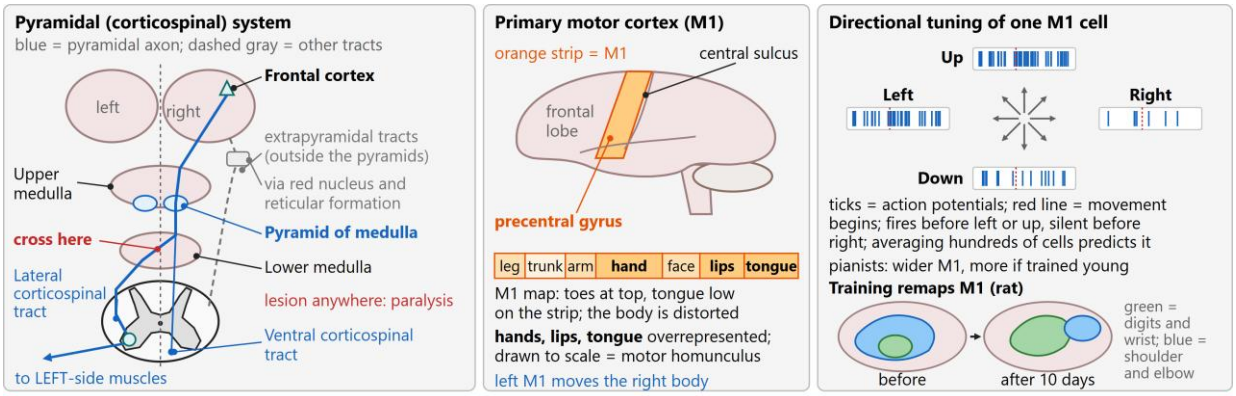
Final common pathway: motor neurons, the sole route by which spinal cord and brain control muscles. [MM p164]

Head muscles are controlled directly by the brain via **cranial nerves**. [MM p167]

Rest of the body: commands from brain and spinal cord via the **somatic nerves**. [MM p167]

The brain sends commands through two major pathways: **pyramidal** and **extrapyramidal** systems. [MM p167]

Pyramidal system (also **corticospinal system**): frontal cortex neurons whose axons form the pyramidal tract. [MM p166, MM p167]



Pyramidal tract crossing in the medulla, M1 strip, and directional tuning [MM p167]

On the figure: pyramid · lower medulla · upper medulla · precentral gyrus · central sulcus · corticospinal tracts · extrapyramidal · directional tuning

Pyramidal tract, path from brain to muscle: [MM p167]

1. Cell bodies in frontal cortex; many in **primary motor cortex (M1)**, the **precentral gyrus**. [MM p167]
2. Axons pass through the brainstem. [MM p167]
3. In the medulla they form the **pyramid**, a wedge-shaped anterior bulge each side of midline. [MM p167]
4. Fibers cross to the opposite side in the medulla. [MM p167]

In cross sections, the pyramids sit in the **upper medulla**; fibers cross in the **lower medulla**. [MM p167]

5. They descend in the lateral and ventral **corticospinal tracts** of the spinal cord. [MM p167]
6. They reach spinal motor neurons or interneurons in the spinal cord. [MM p174]
7. Spinal motor neurons send axons out the **ventral roots** to the periphery. [MM p163]
8. Near the muscle each axon splits into **collaterals** *(axon branches)*, each innervating a separate fiber. [MM p163]
9. At each neuromuscular junction, ACh is released onto the motor end plate; the fiber contracts. [MM p163, MM p164]

Crossing means the right cortex controls the left body side, and left controls right. [MM p167]

Lesions anywhere in the pyramidal tract cause paralysis of muscles controlled by the damaged neurons. [MM p167]

Extrapyramidal system: motor tracts from forebrain to brainstem and spinal cord OUTSIDE the medulla pyramids. [MM p167]

The extrapyramidal system includes the basal ganglia and some closely related brainstem structures. [MM p167]

Many extrapyramidal projections pass through the **reticular formation** and **red nucleus** of midbrain and brainstem. [MM p167]

The basal ganglia are an important point of origin for extrapyramidal projections. [MM p167]

Extrapyramidal lesions do **NOT** prevent moving individual joints and limbs. [MM p167]

But they interfere with spinal reflexes, usually exaggerating them, and with motor fine-tuning. [MM p167]

Spinal cord injuries come from vehicle accidents, violence, falls, and sports injuries. [MM p167]

Complete severing of the cord: immediate and permanent paralysis below the injury level. [MM p168]

Spinal reflexes may or may not be lost, depending on destruction below the injury site. [MM p168]

Reflexes may even become STRONGER from loss of descending inhibition from the brain. [MM p168]

Over **250,000** people in the United States have spinal cord injuries. [MM p168]

Thousands more occur each year, mostly in young people. [MM p168]

Reconnecting the injured spinal cord no longer seems far-fetched. [MM p168]

Primary motor cortex (M1): apparent executive region for initiating movement; a major pyramidal tract source. [MM p168]

Precentral gyrus: frontal strip just in front of the **central sulcus**, crucial for motor control. [MM p168]

M1 is mainly the precentral gyrus, so M1 is part of the frontal lobe. [MM p167, MM p168]

Like S1, M1 occupies one large gyrus and maps the CONTRALATERAL *(opposite side)* body. [MM p168]

Stimulating a discrete region of left M1 moves the matching region on the right body side. [MM p168]

The M1 map is distorted: precisely controlled hands, lips, tongue are overrepresented. [MM p168]

Motor homunculus: a figure drawn with body proportions as represented in M1. [MM p168]

M1 strip order, one end: genitalia, toes, feet, ankle, knee, leg, hip, trunk, neck, shoulder. [MM p167]

M1 strip continues: elbow, wrist, a very large hand area, brow, eyelids, eyeballs, face. [MM p167]

M1 strip other end: lips (large area), jaw, tongue, throat, chewing, salivation. [MM p167]

Homunculus body parts are proportional to the amount of motor cortex for their muscles. [MM p167]

The M1 map is an oversimplification: body regions intermingle because body parts coordinate across M1. [MM p167, MM p168]

Monkey M1 recordings: many cells change firing rate with movement direction. [MM p169]

Each M1 cell fires most for one particular direction (**directional tuning**). [MM p168, MM p169]

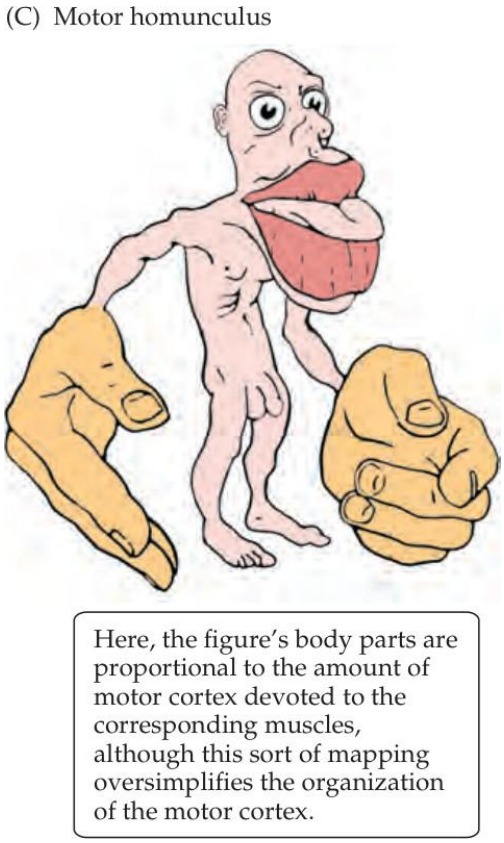
Example cell: silent before arm moves right, fires vigorously before moves left or straight up. [MM p168]

Averaging hundreds of M1 neurons predicts arm movement direction with reasonable accuracy. [MM p169]

Millions of M1 neurons exist, so larger sampling would predict more accurately. [MM p169]

M1 representations are not static: they change with training. [MM p169]

Piano players: M1 is wider than in nonmusicians, especially the hand area. [MM p169]



Motor homunculus with body parts sized by motor cortex [MM p167]

On the figure: motor homunculus

The younger the training started, the larger the gyrus in adulthood: experience expands M1. [MM p169]

TMS *(magnetic stimulation through the skull)*: movements from an M1 patch change with use or learning. [MM p169]

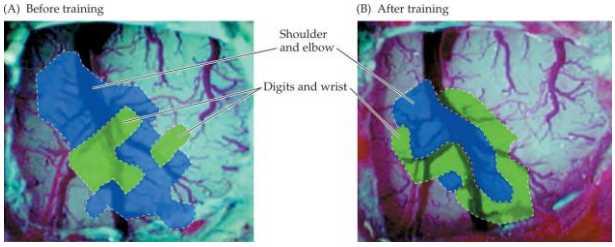
Rats trained **10** days on precise reaching and grasping: motor cortex remapped. [MM p169]

Digit and **wrist** area expanded into areas previously for **shoulder and elbow**. [MM p169]

Premotor cortex: just anterior to M1; actually a mosaic of subareas with distinct properties. [MM p169]

Visual Summary: muscles work in pairs; antagonists oppose, synergists work together. [MM p174]

Visual Summary: action potentials travel along motor neuron axons to the neuromuscular junction, releasing ACh. [MM p174]



Rat motor cortex before and after reach training: digit and wrist area grows [MM p169]

On the figure: wrist · shoulder and elbow

Visual Summary: pyramidal fibers start mainly in M1 and adjacent regions; run directly to spinal cord. [MM p174]

Visual Summary: disproportionate M1 amounts in the precentral gyrus serve finely controlled muscles. [MM p174]

Review, muscles and joints: antagonist and synergist muscles around joints, attached to bones by **tendons**. [MM p162, MM p170]

Review, motor unit: one motor neuron, its axon collaterals, and all fibers it innervates. [MM p164, MM p170]

Review, path: M1, brainstem, medulla crossing, corticospinal tract, motor neuron, ventral root, muscle. [MM p167, MM p170]

Review, M1: precentral gyrus, maps contralateral body, overrepresents precise parts like hands and lips. [MM p168, MM p170]

Review, pyramidal vs extrapyramidal: through the medulla pyramids vs outside them. [MM p167, MM p170]

Review, nonprimary motor cortex: extra motor commands directly and via M1; SMA and premotor. [MM p169, MM p170]

Slow-twitch vs fast-twitch fibers

Fiber type	Contraction	Fatigue
Slow-twitch	Relatively low intensity	Fatigues slowly
Fast-twitch	Contracts strongly	Fatigues quickly

Table source: [MM p163]

Large vs small motor units

Motor unit	Example muscle	Fibers per motor neuron	Fasciculation
Large	Thigh	Hundreds or thousands	Much larger twitch
Small	Face (precise control)	Only a few	Tiny eyelid twitch

Table source: [MM p164]

Pyramidal vs extrapyramidal system

Feature	Pyramidal	Extrapyramidal
Other name	Corticospinal system	None given
Origin	Frontal cortex, mostly M1	Basal ganglia, cerebellum, brainstem nuclei
Route	Through medulla pyramids, crosses there	Outside the medulla pyramids
Relay stations	Direct to spinal cord	Reticular formation, red nucleus
Lesion effect	Paralysis of affected muscles	Exaggerated reflexes, poor fine-tuning

Table source: [MM p167, MM p172, MM p174]

5.3.3 Distinguish between the two main types of sensory feedback from muscles to the nervous system

⚠ **Do not mix up: Muscle spindle senses LENGTH (stretch); Golgi tendon organ senses TENSION (force), not length.** [MM p165]

Brain and spinal cord continually monitor muscles, limb positions, and motor instructions being issued. [MM p164]

Proprioception *(body position sense)*: information about the position and movement of the body. [MM p164]

From Latin proprius, "own," and recipere, "to receive"; called a "sixth sense." [MM p164]

A man whose proprioceptive axons were killed by a virus can still move every muscle. [MM p164]

The man lost information about muscle activity and body position, and light touch below the neck. [MM p164]

Two **proprioceptors** *(body position sensors)*: muscle spindles (length) and Golgi tendon organs (tension). [MM p165]

Muscle spindle: receptor lying parallel to a muscle; fires to the CNS when muscle lengthens. [MM p165]

The spindle is a capsule buried among **muscle fibers**, holding **intrafusal fibers**. [MM p165]

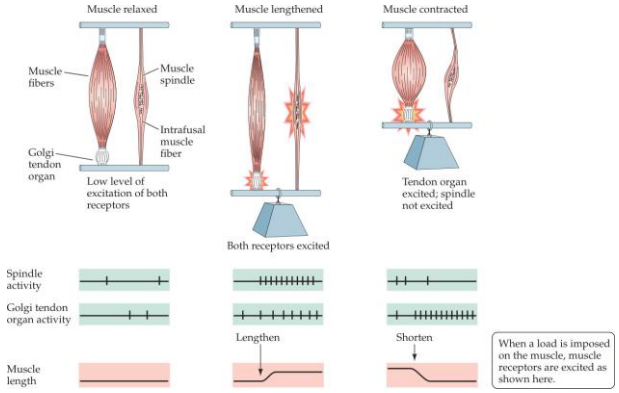
Intrafusal fiber: any small muscle fiber inside a muscle spindle (Latin intra "within," fusus "spindle"). [MM p165]

Muscle stretched beyond **relaxed** state: spindle sensory endings fire action potentials in sensory nerves. [MM p165]

Example: a heavy book handed to you bends the arm down, lengthening the biceps. [MM p165]

Spindle signal tells extent and rate of change in muscle length, so the imposed **load**. [MM p164, MM p165]

A special motor neuron sets intrafusal fiber length to match movements the brain plans. [MM p165]



Spindle and Golgi tendon organ activity when muscle is relaxed, lengthened, or contracted [MM p165]

On the figure: **muscle spindle** · **Golgi tendon organ** · **muscle fibers** · **load** · **relaxed**

Setting intrafusal length calibrates the spindle to the EXPECTED limb position. [MM p165]

Muscle spindle wiring: sensory fibers carry length signals out; a motor fiber sets intrafusal length. [MM p164, MM p165]

Golgi tendon organ: receptor in tendons; fires to the CNS when a muscle contracts. [MM p165]

Golgi tendon organs are especially sensitive to muscle TENSION as the muscle shortens. [MM p165]

Its nerve endings weave through the tendon; strong loads that stretch the tendon excite them. [MM p165]

Main function: monitor force of muscle contractions, a second source of muscle information. [MM p165]

Golgi tendon organs detect overloads that threaten to tear muscles and tendons. [MM p165]

Golgi tendon organs cause reflexive relaxation of the muscle, protecting it (you drop the book). [MM p165]

Another familiar stretch reflex: the knee-jerk, or **patellar reflex**. [MM p165]

Severing sensory fibers from a monkey's arm muscles: monkey stops using that arm. [MM p165, MM p166]

This happens even though motor neuron connections to the muscles are preserved; the arm dangles. [MM p166]

If the good arm is restrained, the monkey learns to use the affected arm, becoming dexterous. [MM p166]

The monkey guides the arm with visual feedback, as the man without proprioception does. [MM p166]

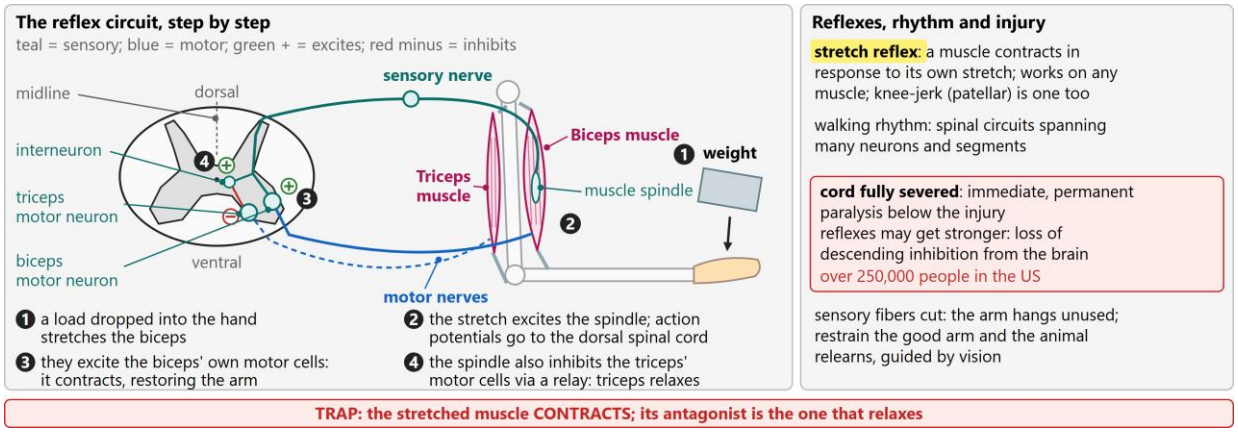
In the dark the man collapses, yet still points to a spot more accurately than controls. [MM p166]

Everyone supplements proprioception with feedback from other senses, like vision. [MM p166]

Spinal cord: lowest hierarchy level; simple circuits produce reflexive responses to sensory stimuli. [MM p166]

Stretch reflex: contraction of a muscle in response to stretch of that same muscle. [MM p166]

A stretch reflex can be elicited by stretching any muscle. [MM p166]



Stretch reflex circuit step by step in the spinal cord [MM p166]

On the figure: stretch reflex · muscle spindle · biceps · triceps · weight

Stretch reflex circuit, in order: [MM p166]

1. A **weight** dropped into the outstretched hand suddenly stretches the **biceps**. [MM p166]
2. Stretch excites the **muscle spindle**, which sends action potentials to the dorsal spinal cord. [MM p166]
3. Spindle action potentials synapse onto biceps motor neurons; biceps contracts, restoring arm position. [MM p166]
4. Spindle also excites interneurons that inhibit **triceps** motor neurons, so the triceps relaxes. [MM p166]

Result: a compensatory movement returns hand and arm to their intended position. [MM p166]

Not all spinal circuits are simple: rhythmic walking uses many neurons across multiple spinal segments. [MM p166]

Visual Summary: spindles (muscles) and tendon organs (tendons) send crucial muscle information to the CNS. [MM p174]

Visual Summary: **efferent** *(outgoing from the CNS)* impulses adjust spindle sensitivity by controlling spindle length. [MM p174]

Review, proprioception: body sense; spindles report length, tendon organs report tension. [MM p164, MM p165, MM p170]

Muscle spindle vs Golgi tendon organ

Feature	Muscle spindle	Golgi tendon organ
Location	Within muscle, parallel to fibers	Woven through the tendon
Senses	Length and rate of change	Tension, force of contraction
Fires when	Muscle is lengthened	Muscle contracts or strong load
Special part	Intrafusal fiber, length set by motor neuron	Nerve endings in tendon
Reflex result	Stretch reflex: same muscle contracts	Overload: reflexive relaxation of muscle

Table source: [MM p164, MM p165, MM p166]

Receptor activity by muscle state

Muscle state	Spindle	Golgi tendon organ
Relaxed	Low excitation	Low excitation
Lengthened by load	Excited	Excited
Contracted (shortened)	Not excited	Excited

Table source: [MM p165]

5.3.4 Discuss the interaction of various cortical and subcortical brain regions in regulating behavior

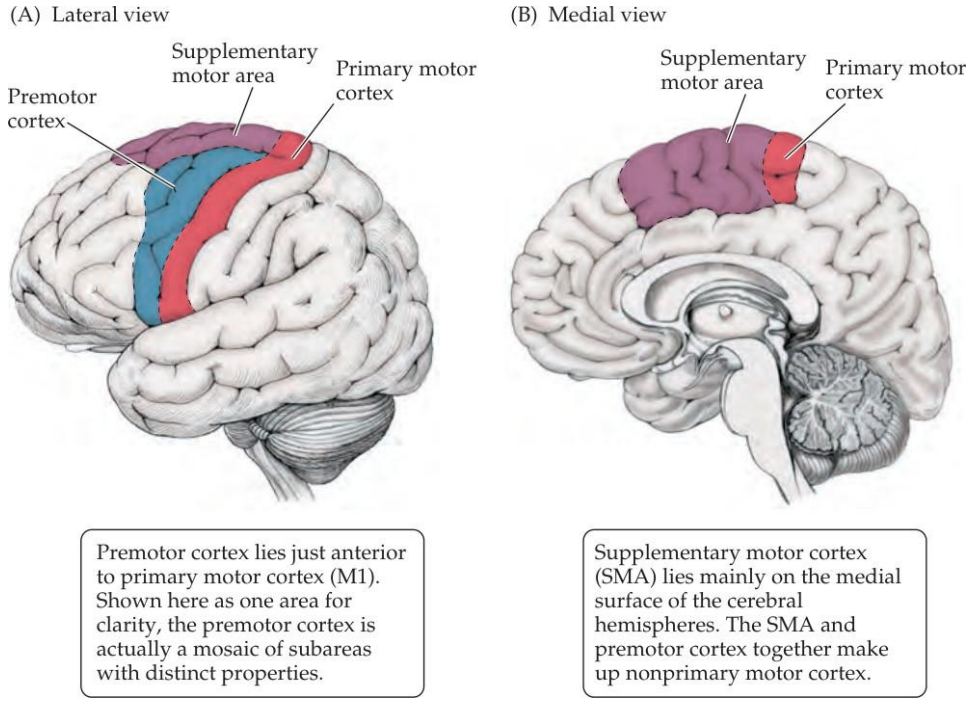
⚠ **Do not mix up: SMA runs INTERNAL preprogrammed sequences; premotor cortex runs sequences guided by EXTERNAL events.** [MM p170]

Nonprimary motor cortex: frontal regions just anterior to M1 that modulate M1 activity. [MM p169]

Nonprimary motor cortex acts directly on brainstem and spinal cord, and indirectly through M1. [MM p169]

Two main nonprimary regions: **supplementary motor area (SMA)** and **premotor cortex**. [MM p169]

SMA: mainly on the medial hemisphere surface; gets basal ganglia input; modulates M1. [MM p169]



Premotor cortex, supplementary motor area and primary motor cortex, lateral and medial views [MM p169]

On the figure: SMA · premotor cortex · M1

SMA: important for INITIATING movement sequences, especially from an internal preprogrammed plan. [MM p170]

Premotor cortex: activated when motor sequences are guided by external events. [MM p170]

Premotor cortex is a mosaic of units controlling behavior categories: defensive movements, feeding behavior. [MM p170]

So premotor areas mostly map BEHAVIORS, rather than specific MOVEMENTS as in **M1**. [MM p170]

Damage to motor cortex (stroke, injury) causes plegia or paresis, usually contralateral. [MM p170]

Plegia: paralysis, the loss of the ability to move. [MM p170]

Paresis: muscular weakness, often from damage to motor cortex. [MM p170]

One-sided forms: **hemiplegia** *(paralysis of one side)* or **hemiparesis** *(weakness of one side)*. [MM p170]

Apraxia *(cannot perform planned complex movements)*: inability to carry out complex movements, though not paralyzed. [MM p170]

In apraxia, weakness is absent, and language comprehension and motivation are intact. [MM p170]

Apraxia comes from damage to nonmotor zones: parietal or frontal association cortex. [MM p170]

From Greek a, "not," and praxis, "action"; several subtypes exist. [MM p170]

Apraxia is a high-level motor-programming problem: cannot work out the needed movement sequence. [MM p170]

Mirror neuron: active when an individual makes a movement AND sees another make it. [MM p170]

Found in premotor subregion **F5**, in ventral premotor cortex of monkeys. [MM p170, MM p171]

Hypothesis tested: F5 neurons encode specific detailed movements rather than muscle contractions. [MM p171]

Experiment: single F5 neurons recorded while a monkey made reaching movements. [MM p171]

F5 neurons fire shortly before a particular hand and arm movement reaching for an object. [MM p170, MM p171]

Different neurons fire during different reaching movements, so they seem to trigger specific movements. [MM p170]

Surprise: they also fire when the monkey watches another monkey or a human do it. [MM p170, MM p171]

Mirror neurons fire as though the monkey were imagining doing the same action. [MM p170, MM p171]

Monkey picks up **raisin**, or watches a human pick it up: the neuron fires both times. [MM p171]

Watching **hand movements** with no **object** to pick up: the **mirror neuron** responds less. [MM p171]

Mirror neurons are also found in adult humans and children, in premotor and other cortex. [MM p170]

Significance: may help understand others' actions; maybe part of a neural system for **empathy**. [MM p170, MM p171]

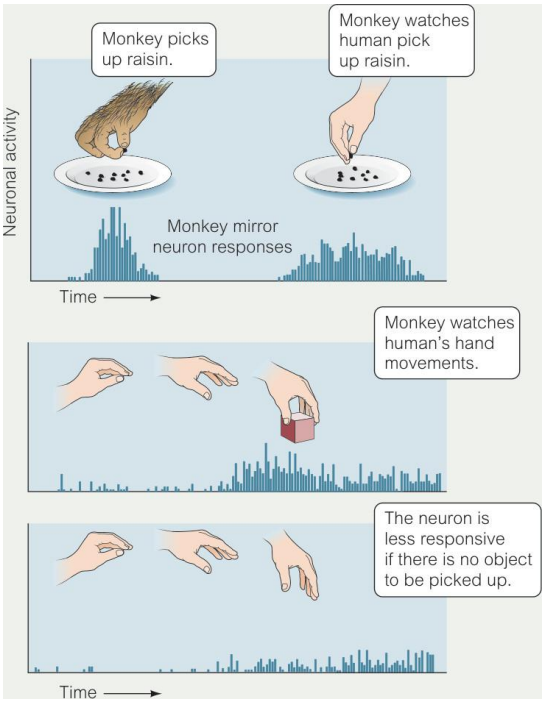
Speculated roles: infant imitation, evolution of language, and other behavior. [MM p170]

Autism spectrum disorder: failure to anticipate others' thinking and actions; maybe a mirror neuron deficit. [MM p170]

Specific functions of mirror neurons remain somewhat controversial. [MM p170]

Extrapyramidal projections are especially important in modulation and ongoing control of movement. [MM p172]

Two of the most important extrapyramidal sources: **basal ganglia** and **cerebellum**. [MM p172]



Mirror neuron firing when a monkey picks a raisin or watches a human do it [MM p171]

On the figure: mirror neuron · raisin · object · hand movements

Basal ganglia: forebrain nuclei deep in the hemispheres: **caudate nucleus**, **putamen**, **globus pallidus**. [MM p172]

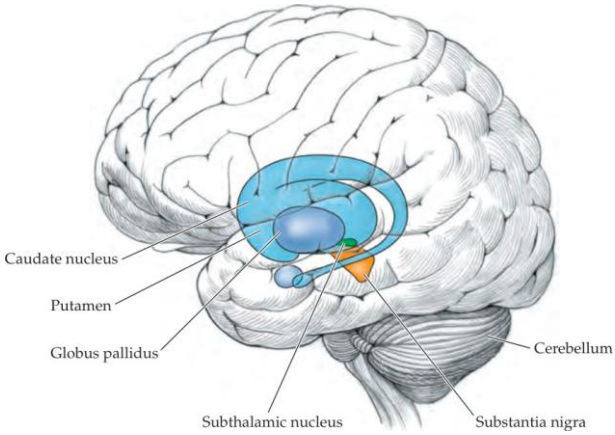
Basal ganglia get strong inputs from the **substantia nigra** and **subthalamic nucleus**. [MM p172]

Basal ganglia loop, in order: [MM p172]

1. Wide expanses of cortex send input toward the basal ganglia. [MM p172]
2. The loop passes through the basal ganglia. [MM p172]
3. Output passes through the thalamus. [MM p172]
4. Back to the cortex, closing the loop. [MM p172]

Basal ganglia help control **amplitude** *(size)* and direction of movement. [MM p172]

Changes in basal ganglia activity appear important for INITIATING movement. [MM p172]



Basal ganglia nuclei, substantia nigra, subthalamic nucleus and cerebellum [MM p172]

On the figure: caudate nucleus · putamen · globus pallidus · subthalamic nucleus · substantia nigra · cerebellum

Much basal ganglia function: modulating activity started by other circuits, such as cortical motor pathways. [MM p172]

Basal ganglia: especially important for movements performed by MEMORY, not those guided by sensory control. [MM p172]

Cerebellum: at the back of the brain, **dorsal** *(behind)* to the pons. [MM p172]

Cerebellum regulates movement centrally and is involved in some forms of learning. [MM p172]

Cerebellum inputs: sensory sources and other brain motor systems. [MM p172]

Sensory inputs: muscle and joint receptors, vestibular, somatosensory, visual, and auditory systems. [MM p172]

Pyramidal and nonpyramidal pathways send inputs to the cerebellum. [MM p172]

Those pathways receive outputs from the deep cerebellar nuclei, all of which are inhibitory. [MM p172]

Cerebellum establishes and fine-tunes neural programs for SKILLED movements. [MM p172]

Especially rapid, repeated movements that become automatic. [MM p172]

Some people appear born without a cerebellum, yet develop normal motor skills. [MM p172]

Presumably due to the great plasticity of the brain during development. [MM p172]

Visual Summary: extrapyramidal = basal ganglia, substantia nigra, brainstem nuclei, and cerebellum. [MM p174]

Brainstem nuclei listed: thalamic nuclei, reticular formation, and red nucleus. [MM p174]

Review, mirror neurons: fire for own and observed movement; may support understanding others. [MM p170, MM p173]

M1 vs SMA vs premotor cortex

Area	Location	Role
M1	Precentral gyrus	Initiates movement; maps specific movements
SMA	Medial hemisphere surface	Starts internally planned sequences; basal ganglia input
Premotor cortex	Just anterior to M1	Externally guided sequences; maps behaviors

Table source: [MM p168, MM p169, MM p170]

Plegia vs paresis vs apraxia

Disorder	Meaning	Damage site
Plegia	Paralysis	Motor cortex
Paresis	Weakness	Motor cortex
Apraxia	Cannot sequence complex movements	Parietal or frontal association cortex

Table source: [MM p170]

Basal ganglia vs cerebellum

Feature	Basal ganglia	Cerebellum
Location	Deep forebrain nuclei	Back of brain, dorsal to pons
Parts or inputs	Caudate, putamen, globus pallidus; nigra input	Sensory plus motor system inputs
Main role	Amplitude, direction, initiation of movement	Fine-tunes skilled, rapid, automatic movements
Best for	Movements performed by memory	Rapid repeated skilled movements
Damage	Parkinson's, Huntington's	Ataxia, decomposition of movement

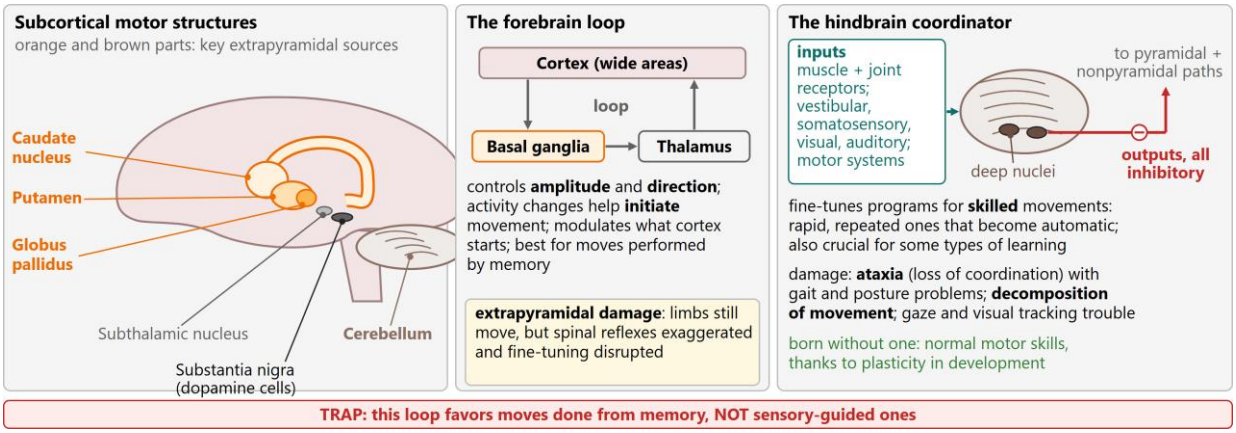
Table source: [MM p172, MM p173]

5.3.5 Describe the behavioral symptoms and underlying pathology of two major motor disorders

⚠ Do not mix up: Parkinson's REDUCES movement (substantia nigra loss); Huntington's causes EXCESSIVE movement (caudate, putamen). [MM p172, MM p173]

Different symptom clusters come from damage to different extrapyramidal structures. [MM p172]

Cerebellar damage effects depend on which part is damaged. [MM p172]



Cerebellar damage and the basal ganglia loop [MM p172]

On the figure: ataxia · decomposition of movement · substantia nigra · caudate nucleus · putamen

Common cerebellar symptoms: abnormal gait and posture, especially **ataxia** of the legs. [MM p172]

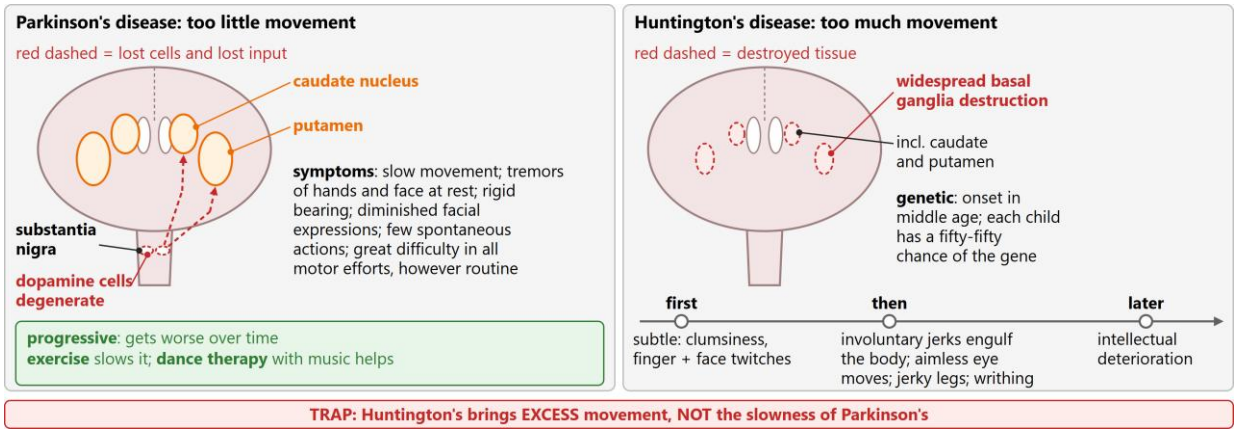
Ataxia: loss of movement coordination, often caused by cerebellar disease. [MM p172]

Decomposition of movement: gestures broken into individual segments instead of executed smoothly. [MM p172, MM p173]

Decomposition of movement is a symptom of cerebellar lesions. [MM p173]

Other cerebellar lesions: difficulty with gaze and visual tracking of objects. [MM p172]

Two basal ganglia diseases reveal extrapyramidal contributions to motor control. [MM p172]



Parkinson's disease versus Huntington's disease [MM p173]

On the figure: Parkinson's disease · Huntington's disease · substantia nigra · caudate nucleus · putamen · dance therapy

Parkinson's disease: degenerative disorder from progressive loss of **dopaminergic** *(dopamine releasing)* **substantia nigra** neurons. [MM p172, MM p173]

Substantia nigra: brainstem structure, a major source of dopamine projections to basal ganglia. [MM p173]

The lost dopamine neurons project to the **caudate nucleus** and **putamen**. [MM p172]

Parkinson's symptoms: slow movement, tremors of hands and face AT REST. [MM p172]

Also a rigid bearing and diminished facial expressions. [MM p172]

Few spontaneous actions; great difficulty in all motor efforts, however routine. [MM p172, MM p173]

Exercise can slow Parkinson's progression. [MM p173]

Dance therapy, using music to encourage movement, helps patients with Parkinson's. [MM p173]

Huntington's disease: genetic disorder, onset in middle age; basal ganglia destruction. [MM p173]

Huntington's causes abrupt, involuntary writhing movements and changes in mental functioning. [MM p173]

First Huntington's symptoms are subtle: clumsiness, twitches in the fingers and face. [MM p173]

As it progresses, a continuing stream of involuntary jerks engulfs the entire body. [MM p173]

Aimless eye movements, jerky leg movements, and body writhing make routine activity hard. [MM p173]

Later stages add intellectual deterioration. [MM p173]

Huntington's pathology: widespread basal ganglia destruction, including caudate nucleus and putamen. [MM p173]

Not just the substantia nigra, as in Parkinson's. [MM p173]

Children of a parent with Huntington's have a fifty-fifty chance of inheriting the gene. [MM p173]

Research into both diseases may pave the way to new therapies. [MM p173]

Review, Parkinson's: slow movement, rest tremor, rigidity; from substantia nigra dopamine cell loss. [MM p172, MM p173]

Review, Huntington's: involuntary jerks and writhing, mental decline; from caudate and putamen destruction. [MM p173]

Review, testing question: a personal choice; the risk of inheriting is fifty-fifty. [MM p173]

Parkinson's vs Huntington's disease

Feature	Parkinson's disease	Huntington's disease
Cause	Degenerative; dopamine neuron loss	Genetic; onset in middle age
Brain damage	Substantia nigra dopamine cells	Widespread basal ganglia: caudate, putamen
Movement	Reduced, slow	Excessive, involuntary jerks
Key signs	Rest tremor, rigidity, flat face	Writhing, twitches, clumsiness
Mental changes	Not mentioned	Later intellectual deterioration
Helps	Exercise, dance therapy	No treatment named

Table source: [MM p172, MM p173]