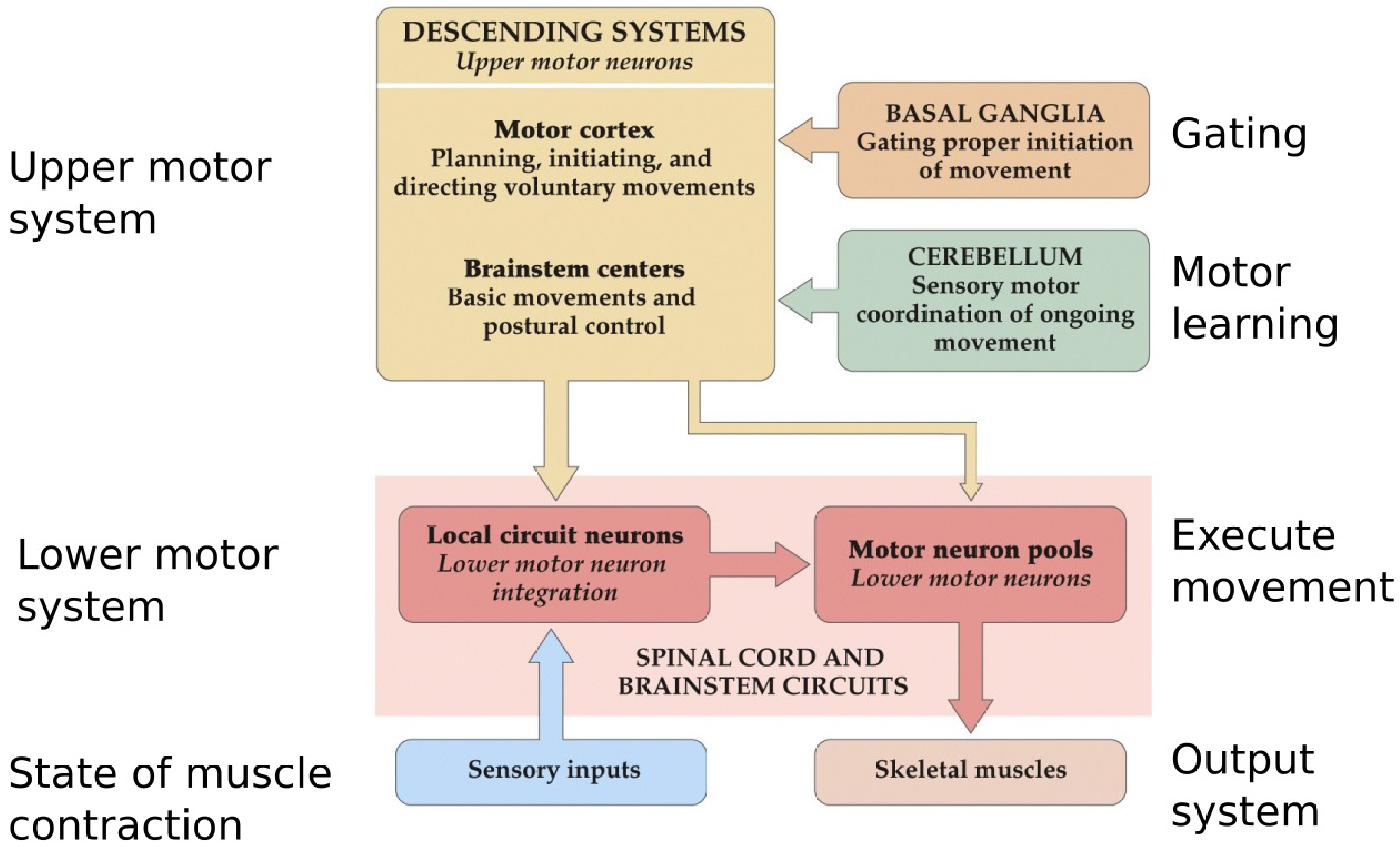
Upper motor neuron control

- Upper motor neuron axons regulate the excitability of lower motor neuron circuits in the brainstem and spinal cord
- Upper motor neurons located in several brainstem centers and a number of cortical areas in the frontal lobe
- Brainstem centers are especially important for postural control
- Motor and premotor cortex are responsible for the planning and precise control of complex sequences of voluntary movements

Speaker notes

posture
: a position of person's body when standing or sitting
: a particular post adopted by an animal, interpreted as a signal of a specific pattern of behavior

Neural systems that control movement



Neuroscience 5e Fig. 16.1

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Speaker notes

We will begin our examination of the pathways in the nervous system that modulate and give rise to volitional control of our skeletal muscles.

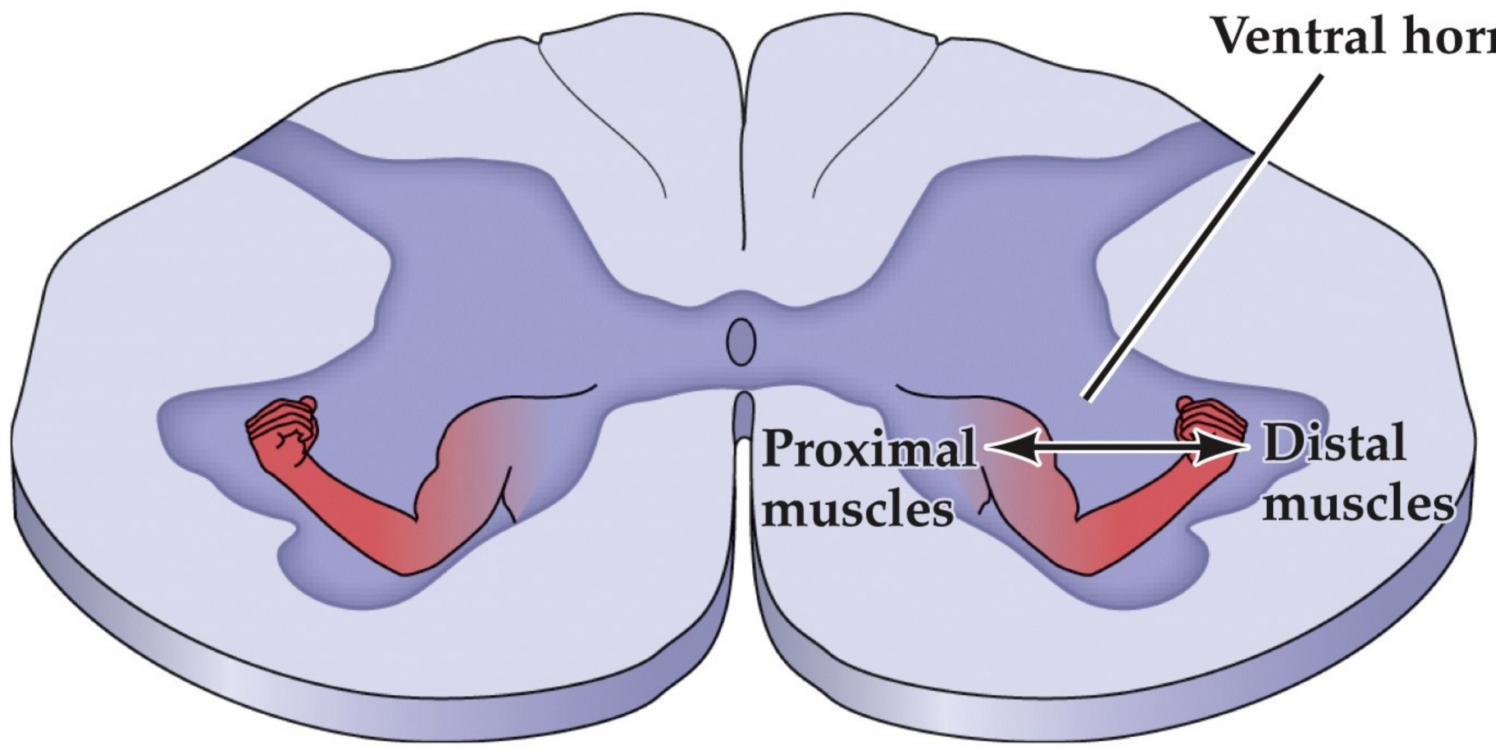
Recall–

lower motor neurons
: are the neurons that make synapses with muscle fibers
: located in ventral horn of the spinal cord gray matter and cranial nerve nuclei of the brainstem

Arrangement of motor neurons and local circuit interneurons within the spinal cord

- Medial ventral horn: motor neuron pools that innervate axial muscles and proximal limb muscles
- Lateral ventral horn: motor neurons that innervate distal limb muscles
- Local circuit interneurons lie in the intermediate zone of the spinal cord grey matter

Somatotopic organization of lower motor neurons



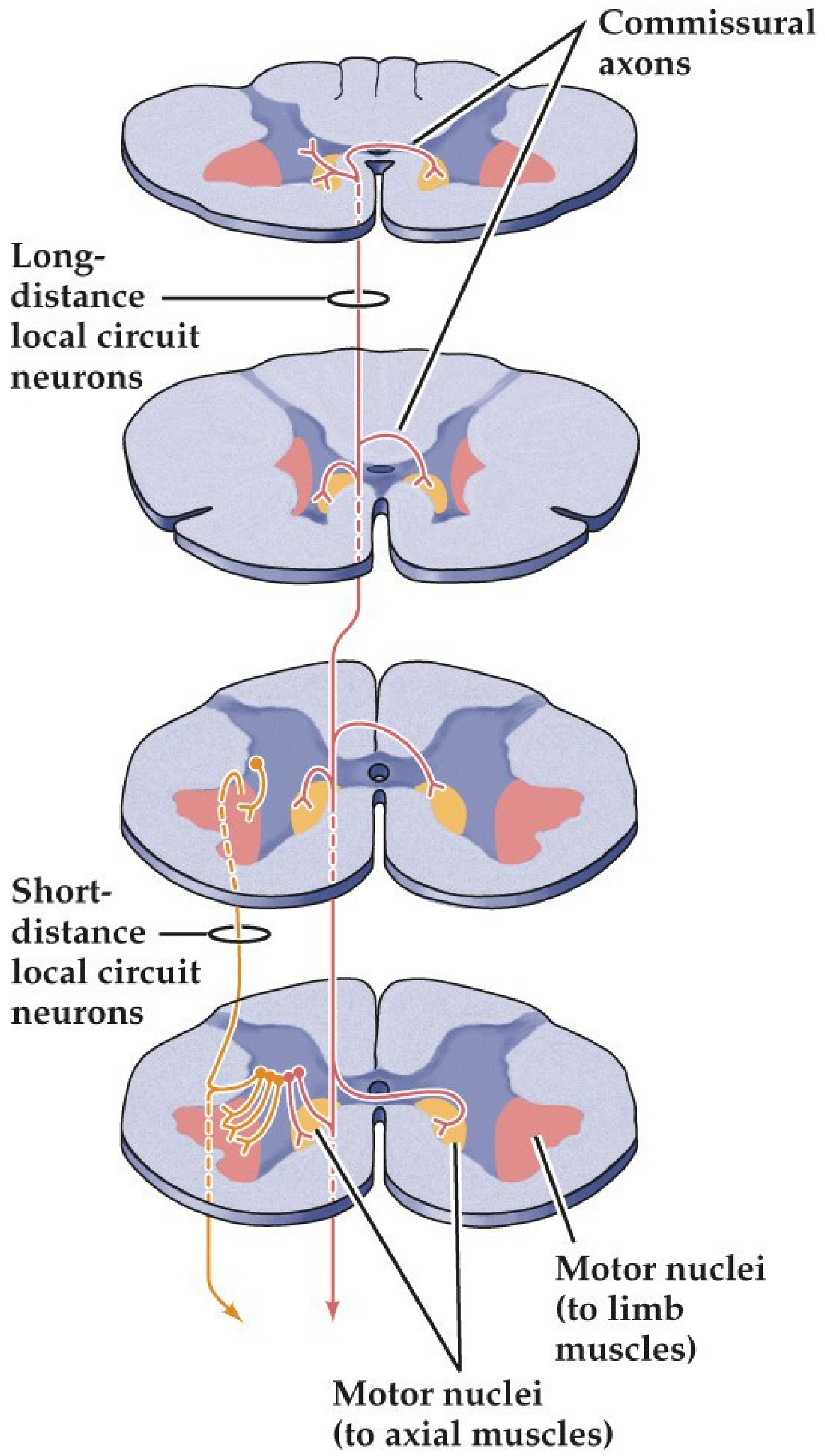
Neuroscience 5e Fig. 16.3

Speaker notes

No notes on this slide.

Arrangement of motor neurons and local circuit interneurons within the spinal cord

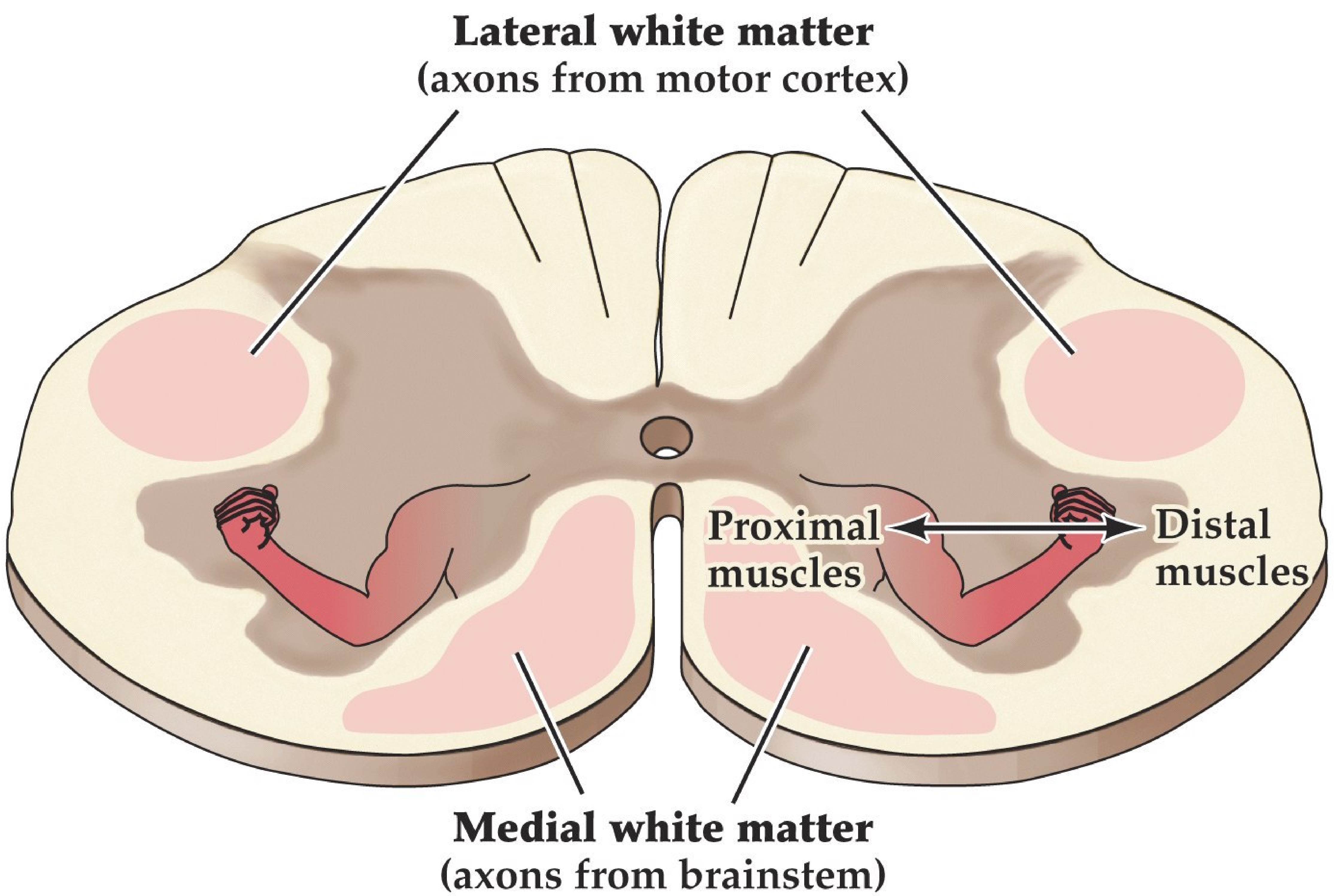
- Medial intermediate zone local circuit neurons project to medial ventral horn motor neurons
- Medial local circuit neurons have axons that may project to targets along the entire length of the cord, and also cross the midline to innervate contralateral side
- Lateral regions of the intermediate zone contain local neurons that synapse with motor neurons in the lateral ventral horn
- Lateral circuit neurons project over a smaller area and do not cross the midline
- Allows distal regions to act independently of each other



Neuroscience 5e Fig. 16.4

Overview of descending motor control

Somatotopic organization of descending upper motor neuron projections



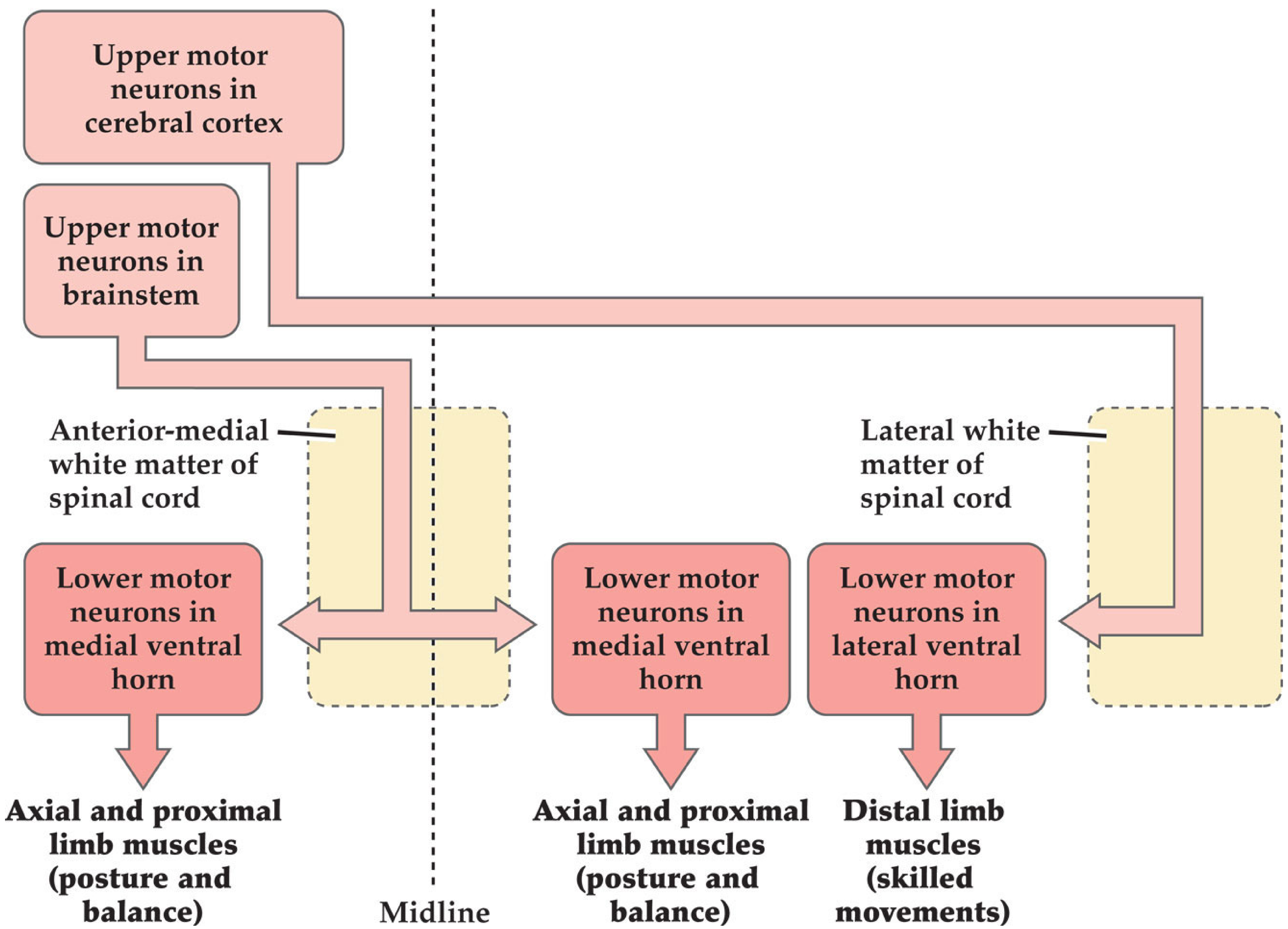
Neuroscience 5e Fig. 17.1

Speaker notes

Somatotopic organization of the ventral horn in the **cervical enlargement**. Locations of descending projections from the motor cortex in the lateral white matter and from the brainstem in the anterior-medial white matter are shown.

Pathways for descending motor control

Upper motor neurons, light red. Lower motor neurons, dark red



Neuroscience 5e Fig. 17.1

Speaker notes

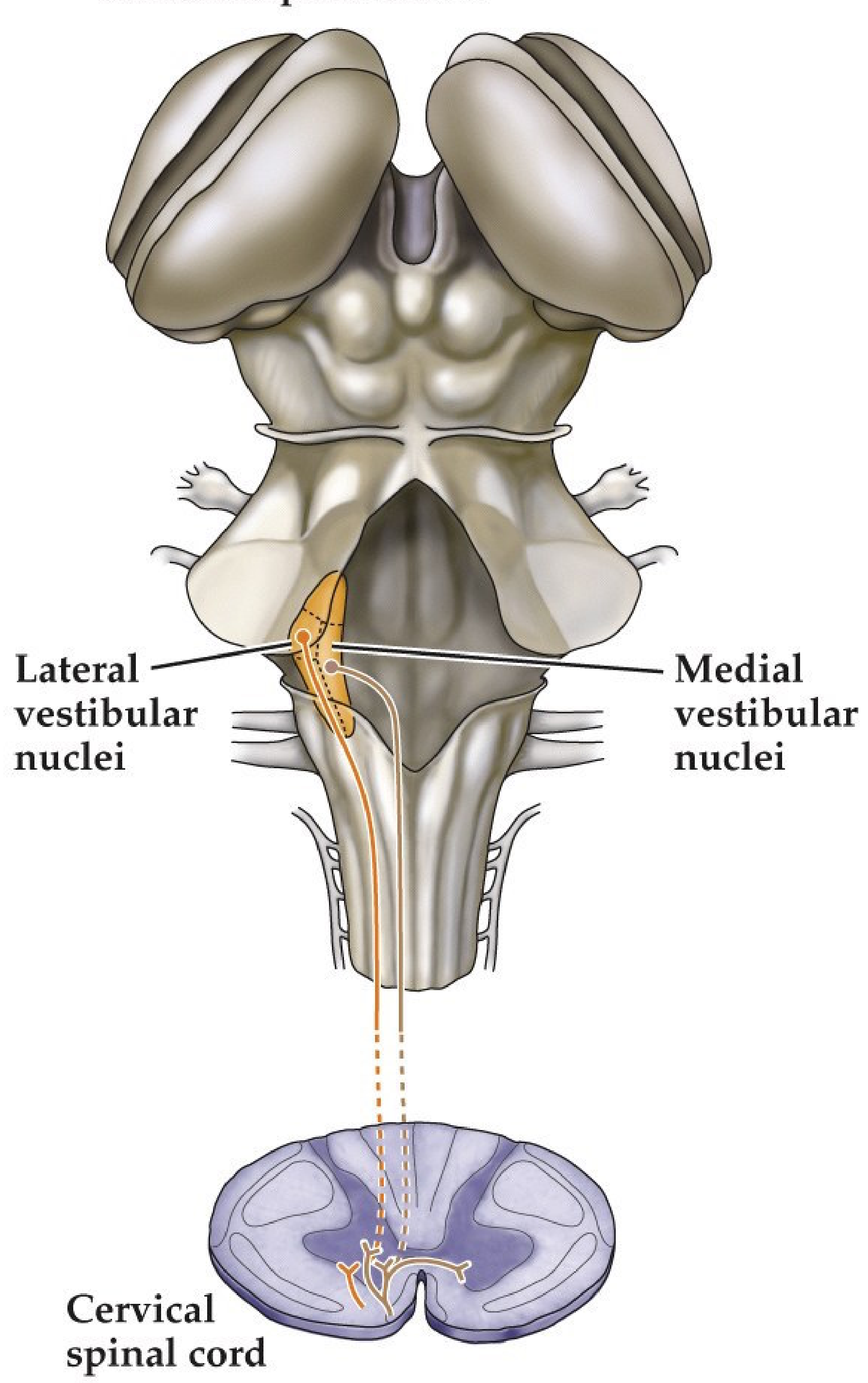
Medial ventral horn has lower motor neurons for posture, balance, and orienting movements of head and neck during shits of visual gaze. Receive descending input from the pathways originating mainly in the brainstem, course through the anterior medial white matter of the spinal cord and terminate bilaterally.

Lateral ventral horn contains lower motor neurons that mediate skilled voluntary movements of the distal extremities. Receive descending projection from the contralateral motor cortex via lateral division of the corticospinal tract.

Next, lets discuss the upper motor neurons of the brainstem.

Medial brainstem pathways modulate the action of motor neurons in the ventromedial area

- Vestibular nuclei
  - Receive information from inner ear for body position and balance
  - Project to medial regions of spinal gray matter (**vestibulospinal tract**)
  - Controls axial muscles and proximal limbs to correct for postural instability (feedback control)



Neuroscience 5e Fig. 17.11

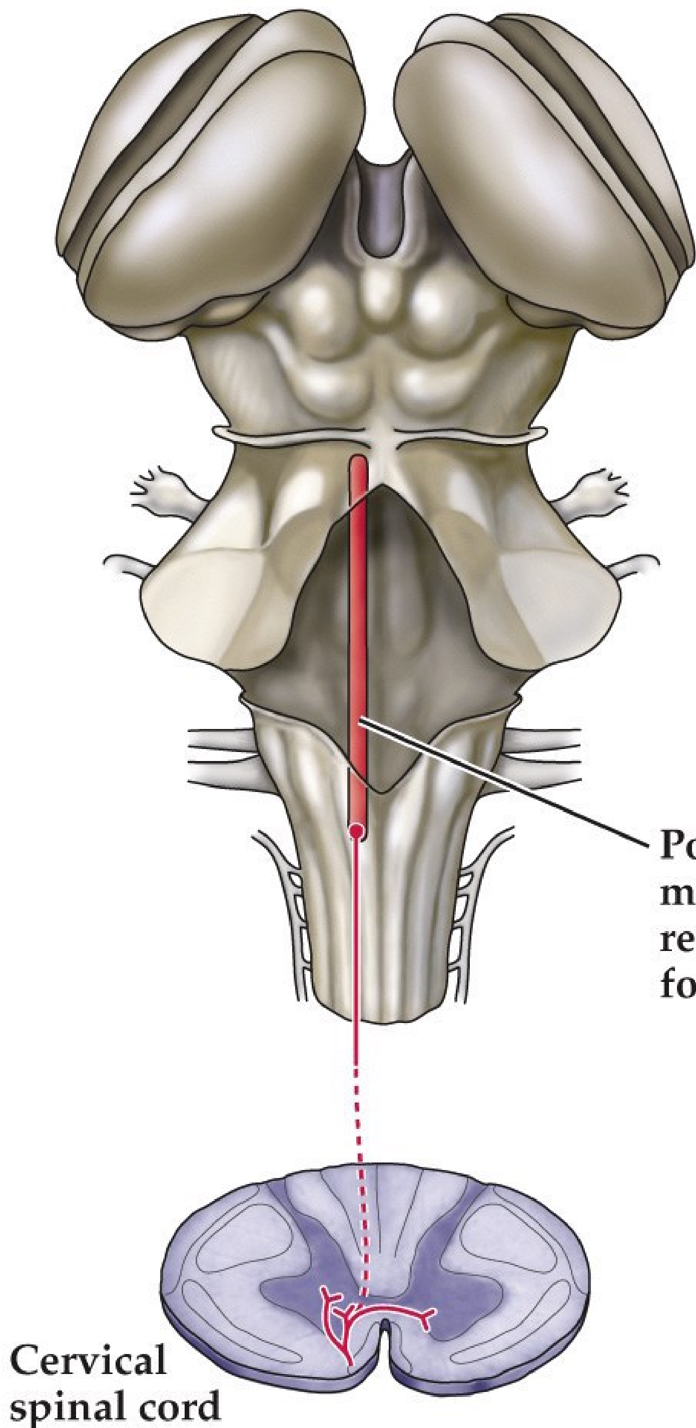
Speaker notes

Info from semicircular canals in inner ear. Provides sensory information for self motion, head position, and body position relative to gravity. It is neural feedback for postural control

There are actually both crossed and uncrossed vestibular projections.

Medial brainstem pathways modulate the action of motor neurons in the ventromedial area

- Reticular formation
  - Complex network of circuits located in the core of the brainstem-from midbrain to medulla
  - Receives input from motor cortex, hypothalamus, brainstem
  - Project to medial regions of spinal gray matter (**reticulospinal tract**)
  - Important for feedforward postural control (anticipating instability)



Neuroscience 5e Fig. 17.11

Speaker notes

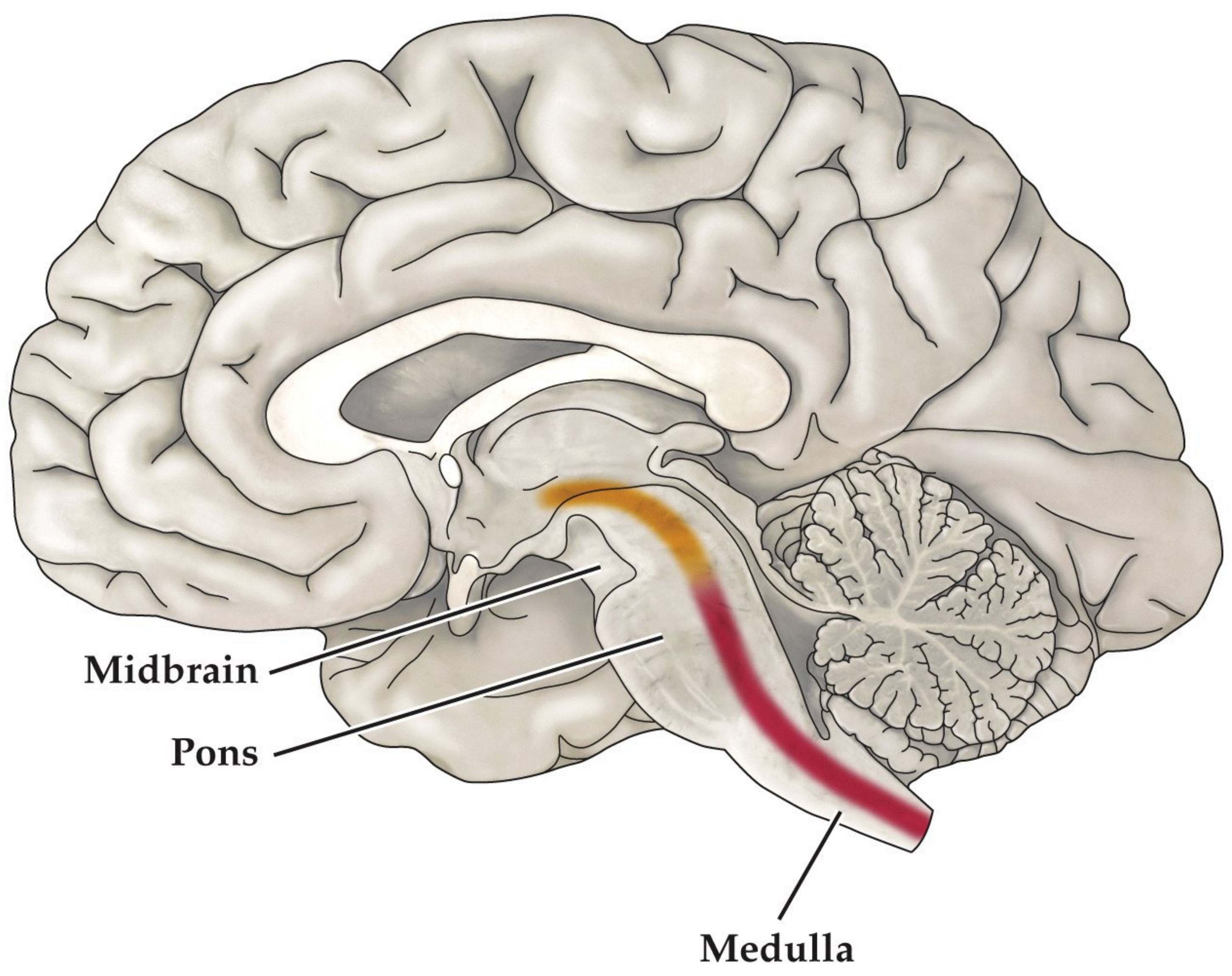
Reticular formation neurons functions
: cardiovascular (regulate output of nucleus ambiguous) and respiratory control (ventrolateral medulla)
: sensory motor reflexes
: coordination of eye movements
: regulation of sleep and wakefulness
: coordination of limb and trunk movements
: netlike, difficult to recognize distinct neuronal clusters
: does not have a uniform function as thought classically

- rostral portions (mesencephalic and pontine) of reticular formation modulate forebrain activity (Moruzzi and Magoun EEG Clin. Neurophys 1949)
  - cholinergic neurons (superior cerebellar peduncle) and noradrenergic neurons (locus coeruleus) and serotonergic neurons (raphe nuclei)
  - "reticular activating system"
- caudal portions involved in premotor coordination of lower somatic and visceral motor neuron pools

Feedforward postural control. Stabilization during ongoing movements.

Reticulospinal tract is uncrossed (except for commisural spinal segment collaterals?)

Location of the reticular formation in relation to some other major landmarks



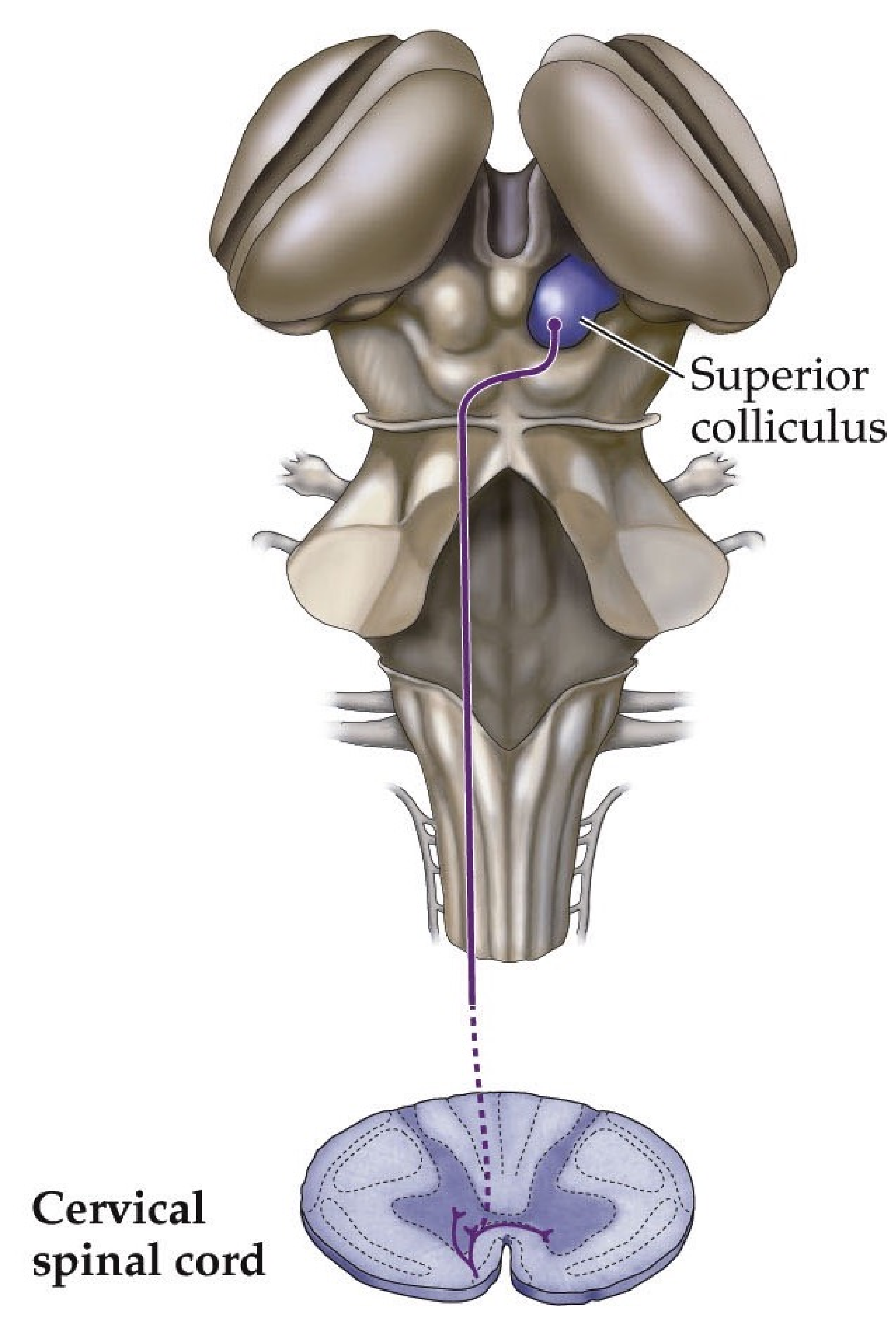
Neuroscience 5e Box 17D

Speaker notes

- rostral portions (gold, mesencephalic and pontine) of reticular formation modulate forebrain activity (Moruzzi and Magoun EEG Clin. Neurophys 1949)
  - cholinergic neurons (superior cerebellar peduncle) and noradrenergic neurons (locus coeruleus) and serotonergic neurons (raphe nuclei)
  - "reticular activating system"
- caudal portions (red) are upper motor neurons involved in coordination of lower somatic and visceral motor neuron pools

Medial brainstem pathways modulate the action of motor neurons in the ventromedial area

- Superior colliculus
  - Projects to medial cell groups in the cervical spinal cord
  - Direct projections to spinal neurons (colliculospinal tract)
  - Indirect projections– most collicular mediated spinal influence is relayed through reticular formation
  - Axial musculature control of neck for performing orienting movements of head as well as eye movements (saccades)



Neuroscience 4e Fig. 17.2

Speaker notes

colliculo- or tectospinal tract. There are actually both crossed and uncrossed tectal projections.

Also rubrospinal tract in non-human primates and other mammals. Red nucleus in midbrain tegmentum. Axons terminate in lateral ventral horn region (distal extremities control). Few if any large neurons in red nucleus in human and don't project to spinal cord. Instead project to inferior olive in human (for learning signals/error control with cerebellum)

Feedforward processing

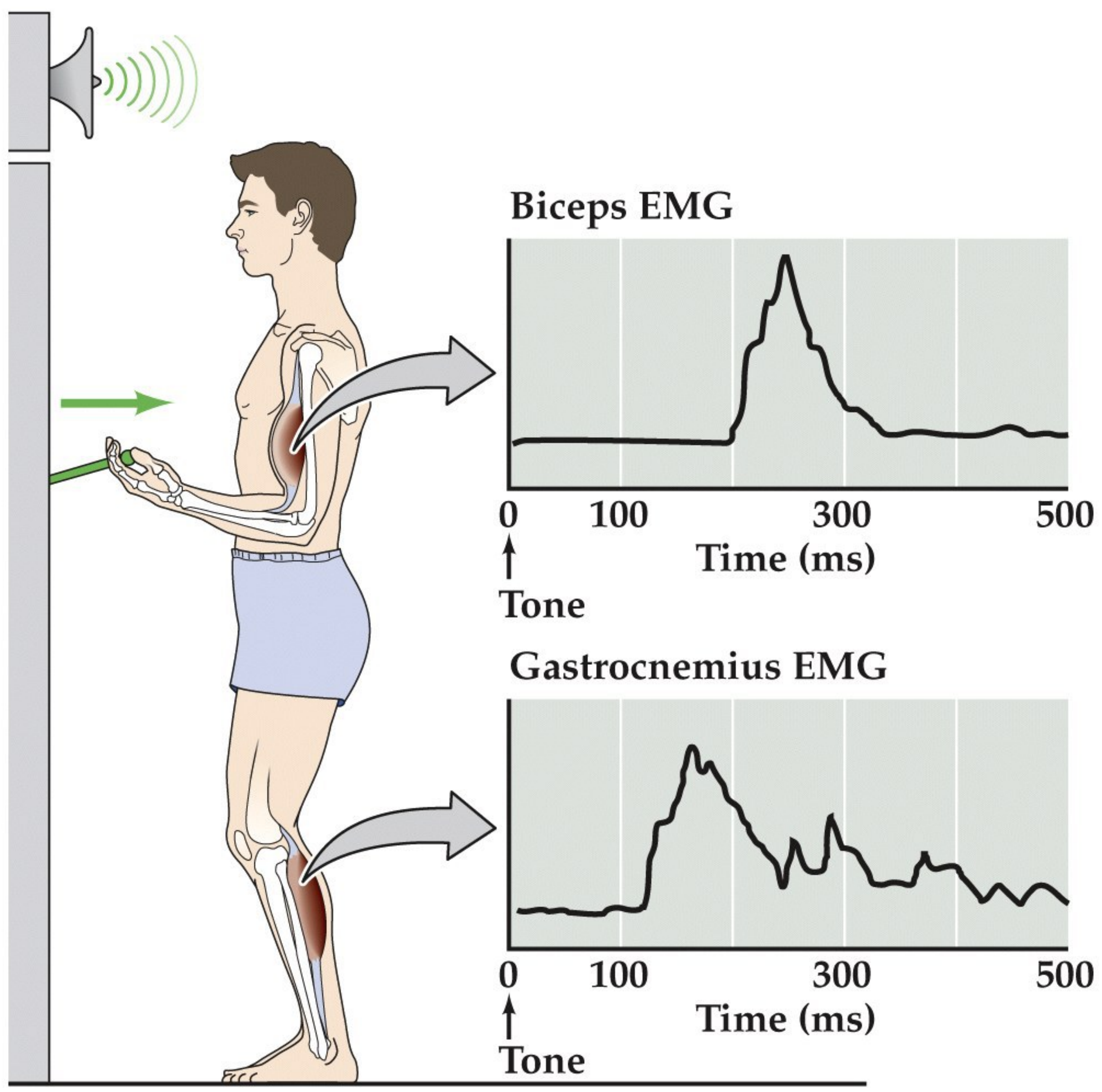
- Able to predict changes in posture, and generate an appropriate stabilizing response
- Some muscles fire in anticipation of a need for postural adjustment
- **Reticulospinal tract** important for this process. If it is severed in a cat, no change in compensatory muscles occur during the process
- Stimulate motor cortex in the right place can induce paw lifting, and several limb muscles to fire. Inhibition of the reticulospinal tract will allow the paw to move but will prevent the movement of other limbs

Speaker notes

No notes on this slide.

Reticulospinal tract function– anticpate body posture control

Upon cue (audible tone) for pulling, gastrocnemius contracts before biceps. EMG: electromyography. Measure extracellular muscle APs



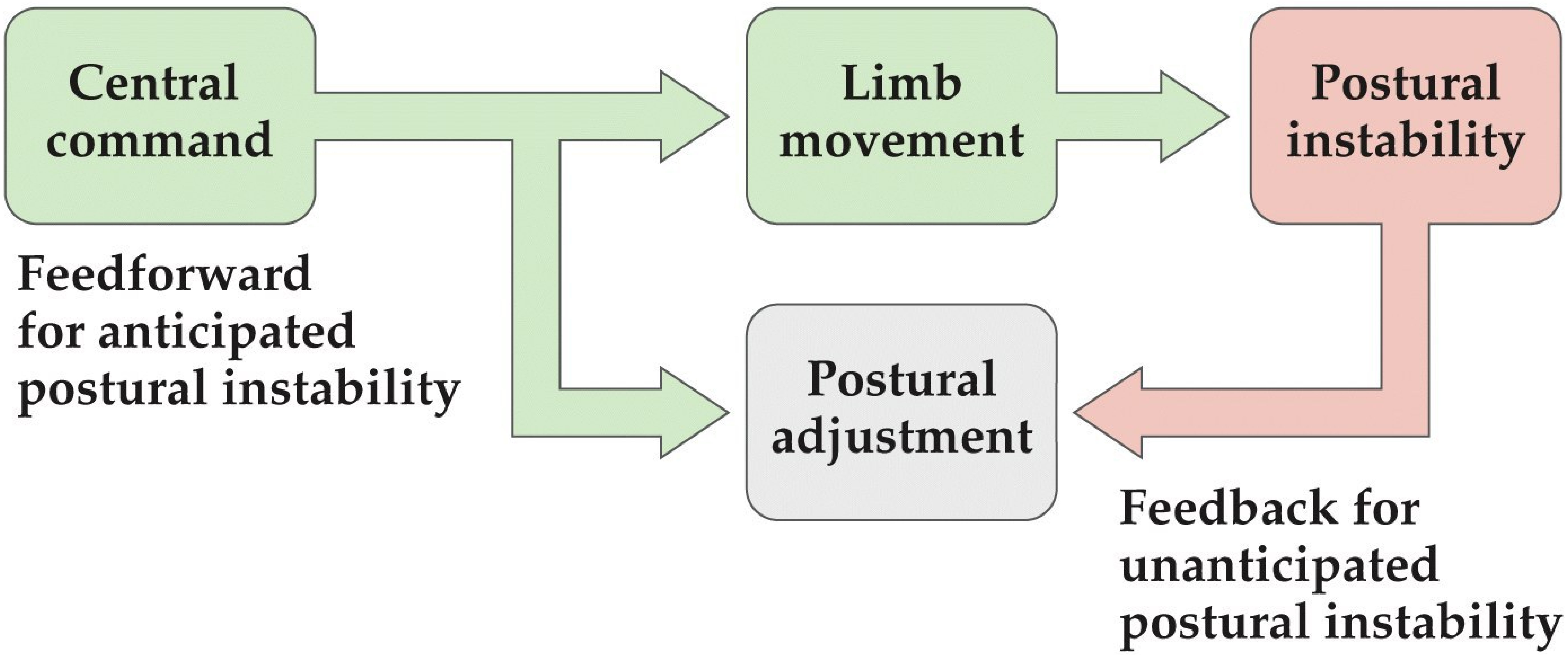
Neuroscience 5e Fig. 17.13

Speaker notes

Severed reticulospinal tract will allow biceps to fire but will not allow the gastrocnemius to fire for posture.

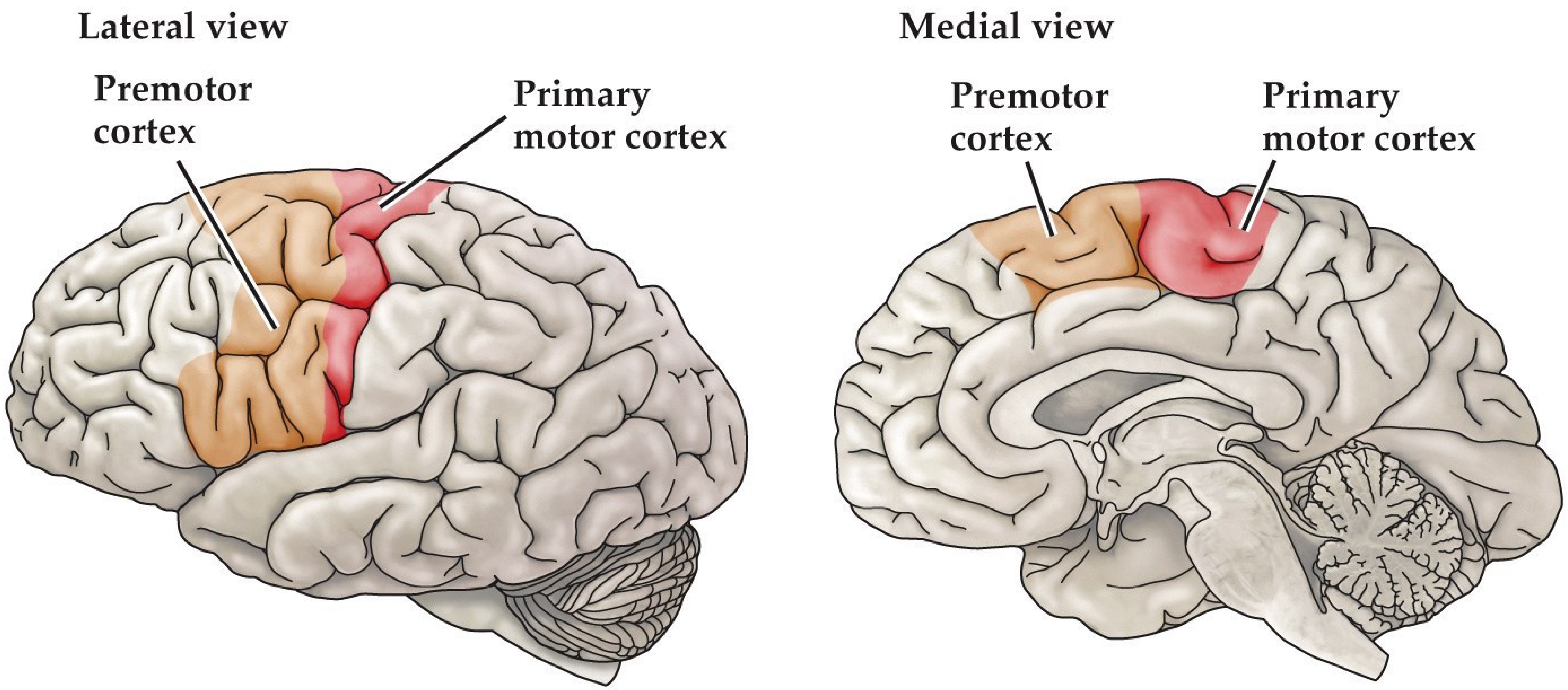
Feedforward and feedback mechanisms of postural control

Feedforward activity for postural control (green) precedes limb movement (e.g. reticulospinal tract). Feedback activity for postural control initiated by sensory inputs detecting instability (e.g. vestibulospinal tract).



Neuroscience 5e Fig. 17.14

Primary motor cortex and premotor cortex are in the frontal lobe



Neuroscience 5e Fig. 17.2

Speaker notes

No notes on this slide.

Primary motor cortex

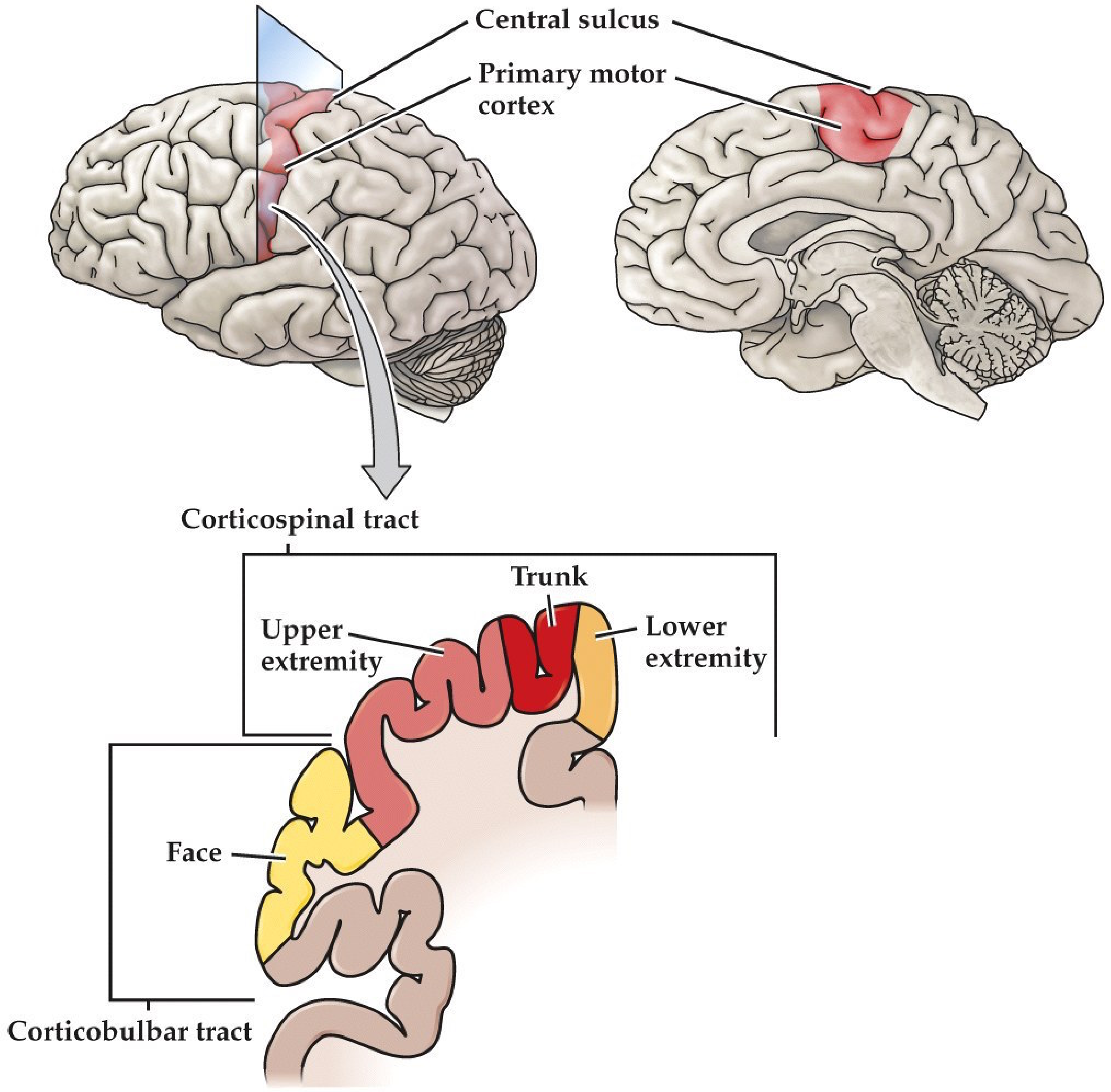
- Located in the precentral gyrus
- Receives inputs from S1, posterior parietal structures (incorporates multiple sensory modalities, used for planning)
- Controls contralateral side of the body
- Topographic organization- body represented across the medial-lateral axis. More space given to areas of fine motor control (e.g. hands)

Speaker notes

Multiple neurons can get the same muscle to fire- not located in exact same place in cortex

Primary motor cortex

topographic representation in motor cortex



Neuroscience 5e Fig. 17.5

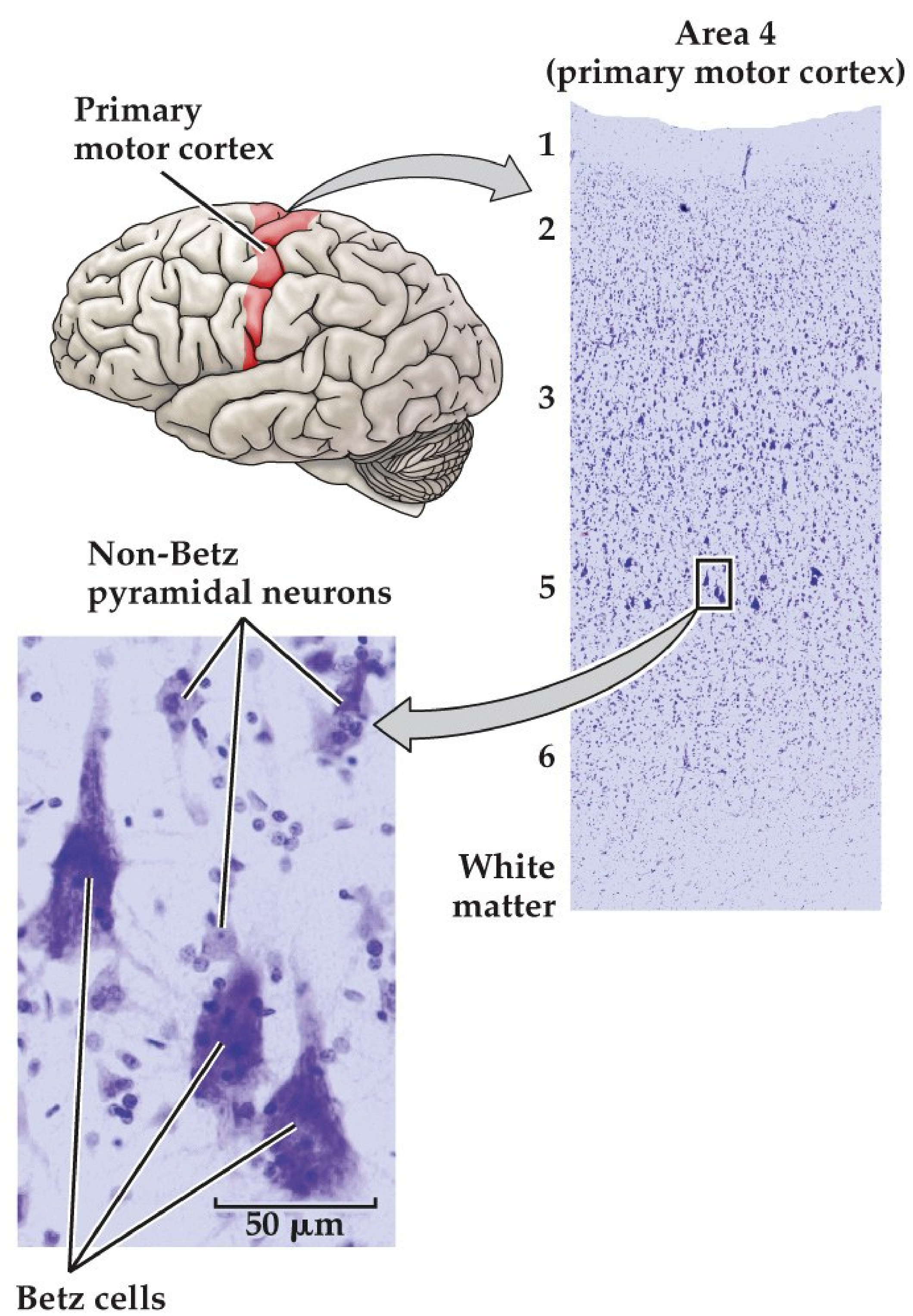
Speaker notes

Somatotopic representation across S1 and M1

Wilder Penfield 1940s

Motor cortex

- Located in the frontal lobe
- Several adjacent and interconnected areas
- Primary motor cortex located in the precentral gyrus
- Gets input from sensory cortex, basal ganglion and cerebellum
- Has 6 layers, layer V is the output layer (pyramidal cells, including the large Betz cells consisting of about 5% of projection to spinal cord and concerned with fine distal movements)
- Primary pathway- the corticospinal tract. Axons cross in the caudal medulla, and innervate in lateral ventral horns



Neuroscience 5e Fig. 17.3

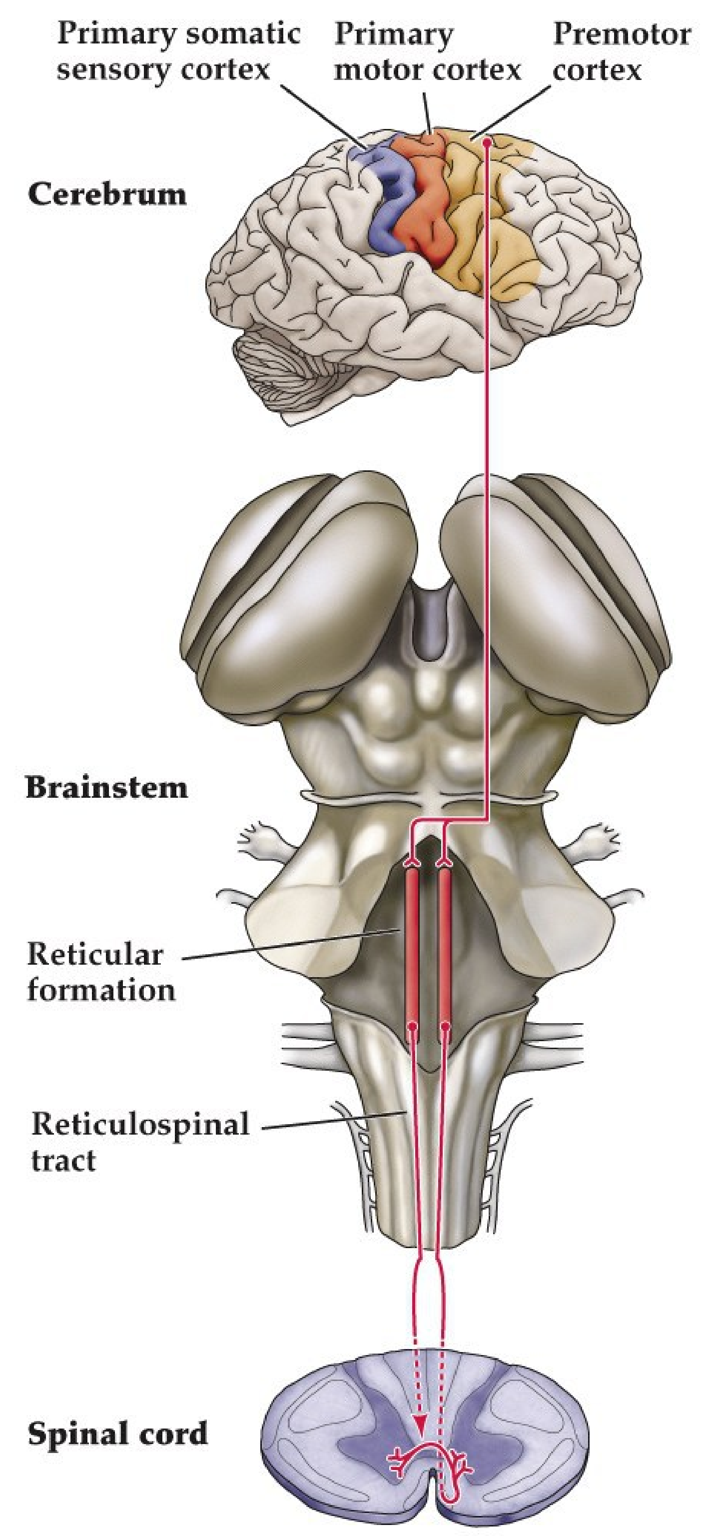
Speaker notes

No notes on this slide.

Pathways from the motor cortex to the spinal cord

- Corticospinal tract (direct pathway)
  - Direct pathway: fine motor control (e.g. fingers)
- Corticobulbar tract (indirect pathway. "bulbar" refers to brainstem nuclei)
  - Indirect pathway: postural adjustments, especially for axial and proximal muscles. Facial movements

Corticobulbar pathway



Neuroscience 5e Fig. 17.5

Speaker notes

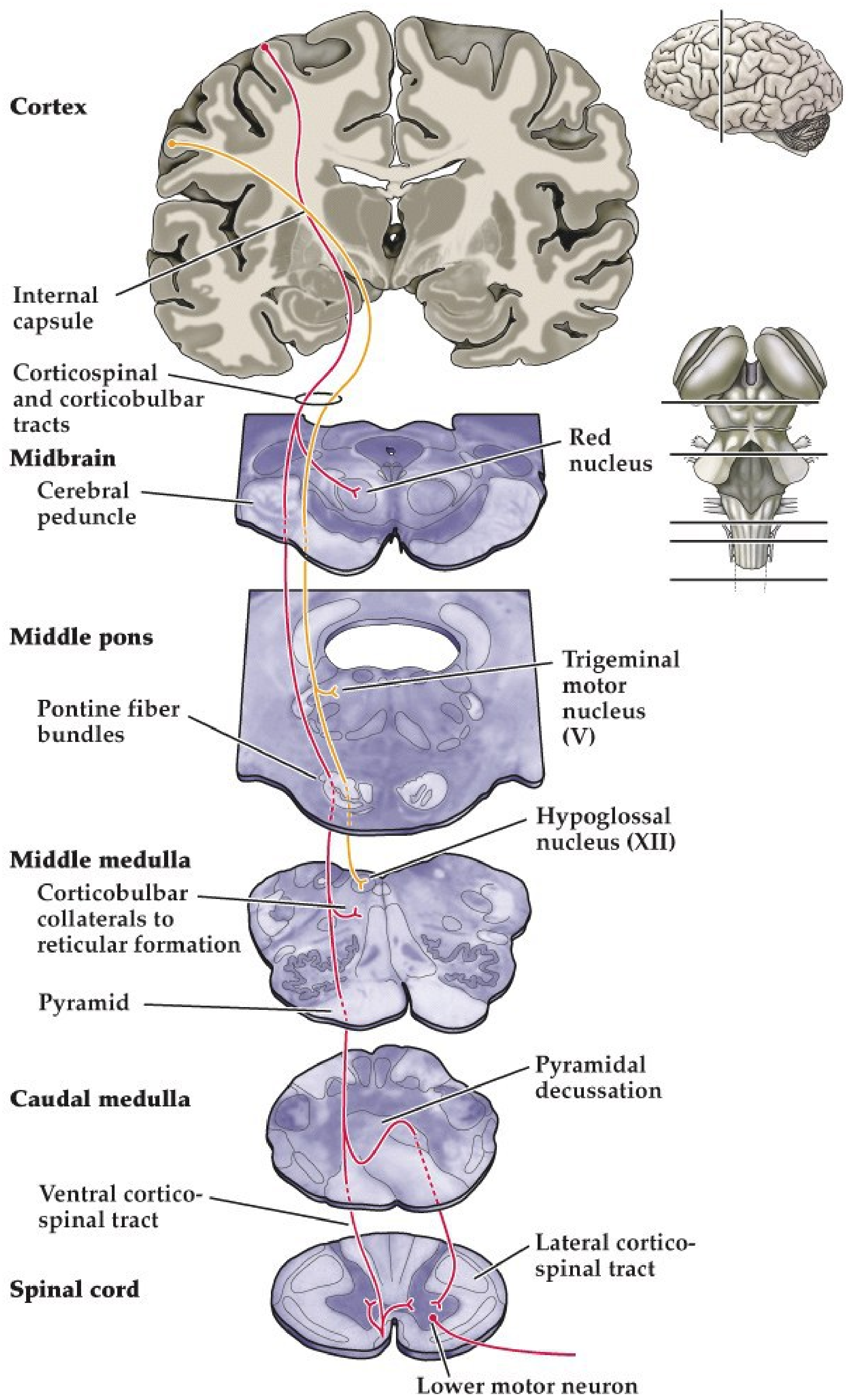
90% of corticaospinal axons at caudal end of medulla cross (decussate, lateral corticospinal tract). 10% remain ipsilaterally (ventral corticospinal tract).

most corticobulbar inputs (except lower face and tongue) terminate bilaterally.

maps: muscle, movement sequences, intention?

H. Kuypers experiments
: rhesus monkey
: test function of direct vs indirect pathways from motor cortex
: transect spinal cord at medulla, leaving indirect path to spinal cord via brainstem reticular formation
: stand walk run climb intact with proximal and axial muscles, but precise distal limb usage with hands impaired (e.g. can't pick up food objects). Independent use of fingers doesn't return

The corticospinal and corticobulbar tracts



Neuroscience 5e Fig. 17.4

Speaker notes

Corticobulbar is yellow, corticospinal in red. Note that most corticospinal axons cross the midline in the caudal medulla. Corticobulbar is for facial muscles.

internal capsule to cerebral peduncle at base of midbrain to scatter among pontine fibers and basal pontine gray matter then coalesce at ventral surface medulla to form medullary pyramids

corticobulbar axons terminate primaryly on local circuit neurons rather than brainstem motor neurons

For animals with little silled movements of distal limbs/paws corticospinal projections mostly directed to the dorsal horn of spinal cord to modulate proprioceptive and mechanosensory inputs relevant to body movements. Projection to the ventral horn from corticospinal tract largest for animals with skilled fractionated movements of hands and forepaws.

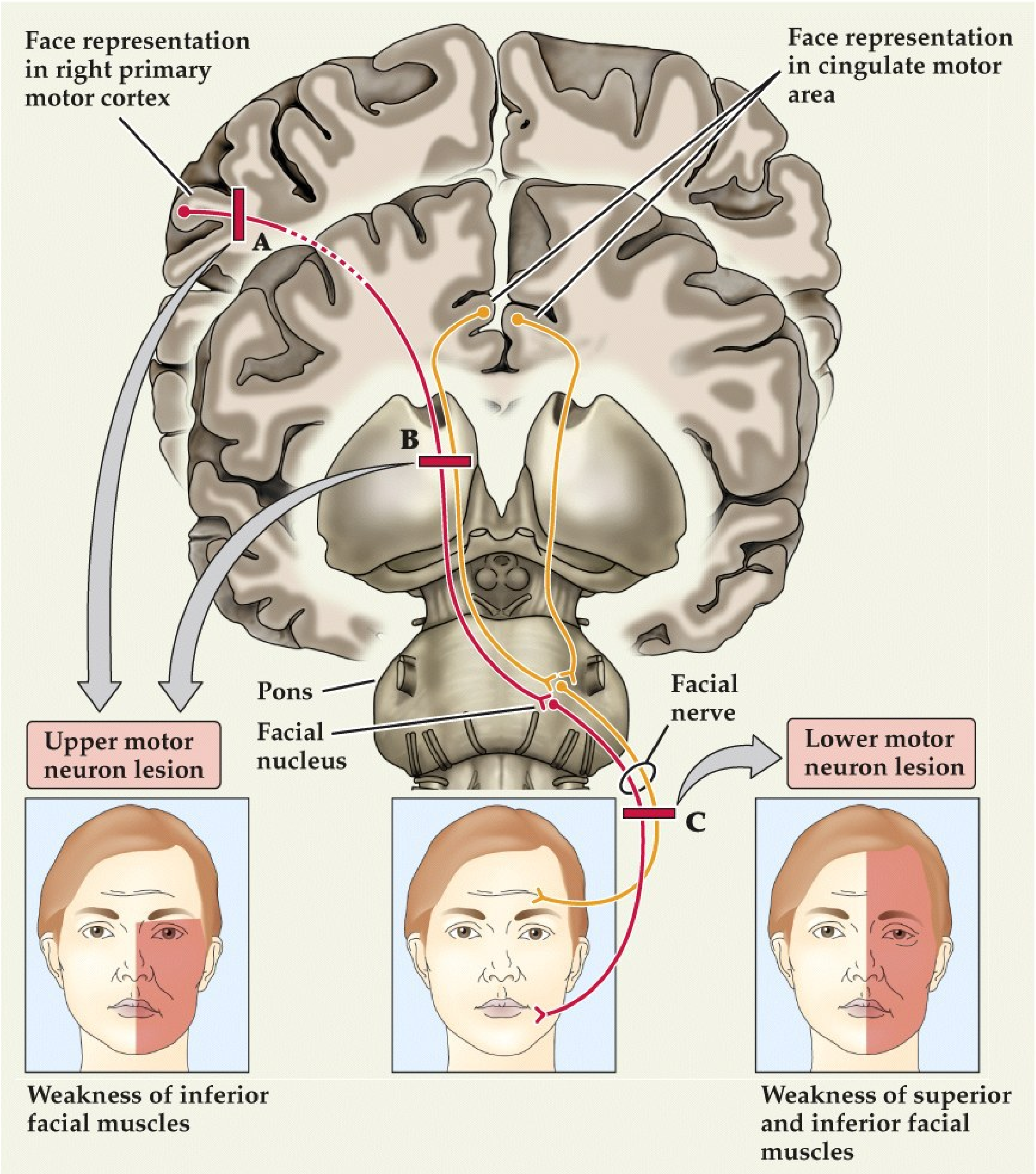
Facial pathway

- The primary pathway to facial muscles is within the corticobulbar pathway
- Projection from motor cortex to motor nuclei in brainstem that control facial muscles
- Some of these projections are bilateral and some only contralateral
- Important for diagnosis where motor damage occurs after a stroke

Speaker notes

anterior cingulate gyrus, region important for emotional processing sparing in of superior facial muscles in B compared to C. Because of ACC has

Patterns of facial weakness and their importance for localizing neurological injury



Neuroscience 5e Box 17A

Speaker notes

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Motor maps

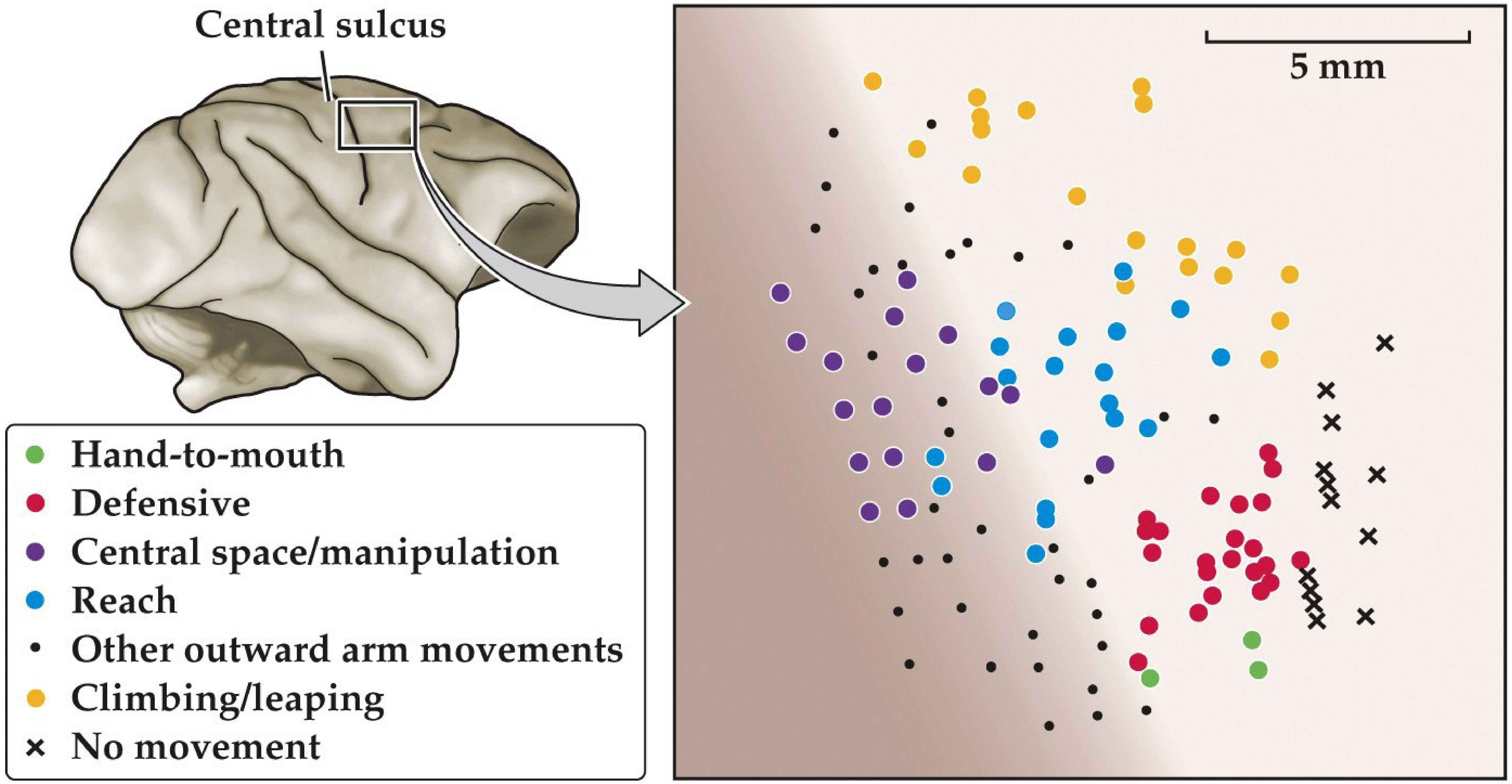
- A stimulation of a neuron in the primary motor cortex will get multiple muscles to fire, and will inhibit other muscles
- Stimulating any of multiple upper neurons can get the same muscle to fire
- The "receptive field" of a upper motor neuron has to do with organized movements rather than specific muscle groups
- Upper motor neurons therefore act upon more than one motor pool

Speaker notes

Maps of musculature or maps of movements?

What do motor maps represent?

microstimulation of awake, behaving monkeys



Neuroscience 5e Box 17B. Graziano et al., J. Neurophysiol 2005

Speaker notes

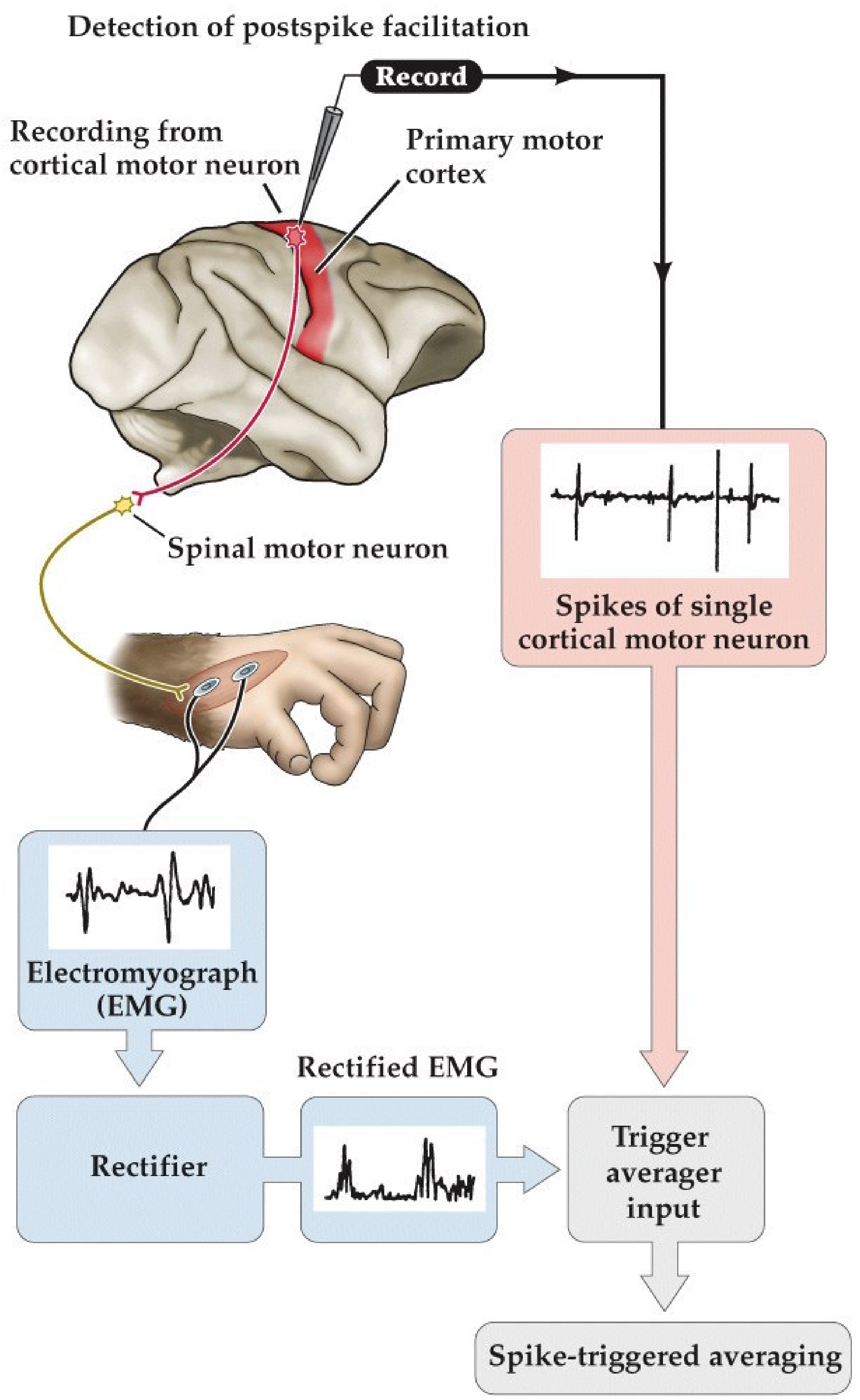
Topographic distribution of microstimulation sites that evoke behaviorally relevant movements in a macaque monkey.

Shaded region in map of stimulation sites indicates cortex folded into the anterior bank of the central sulcus.

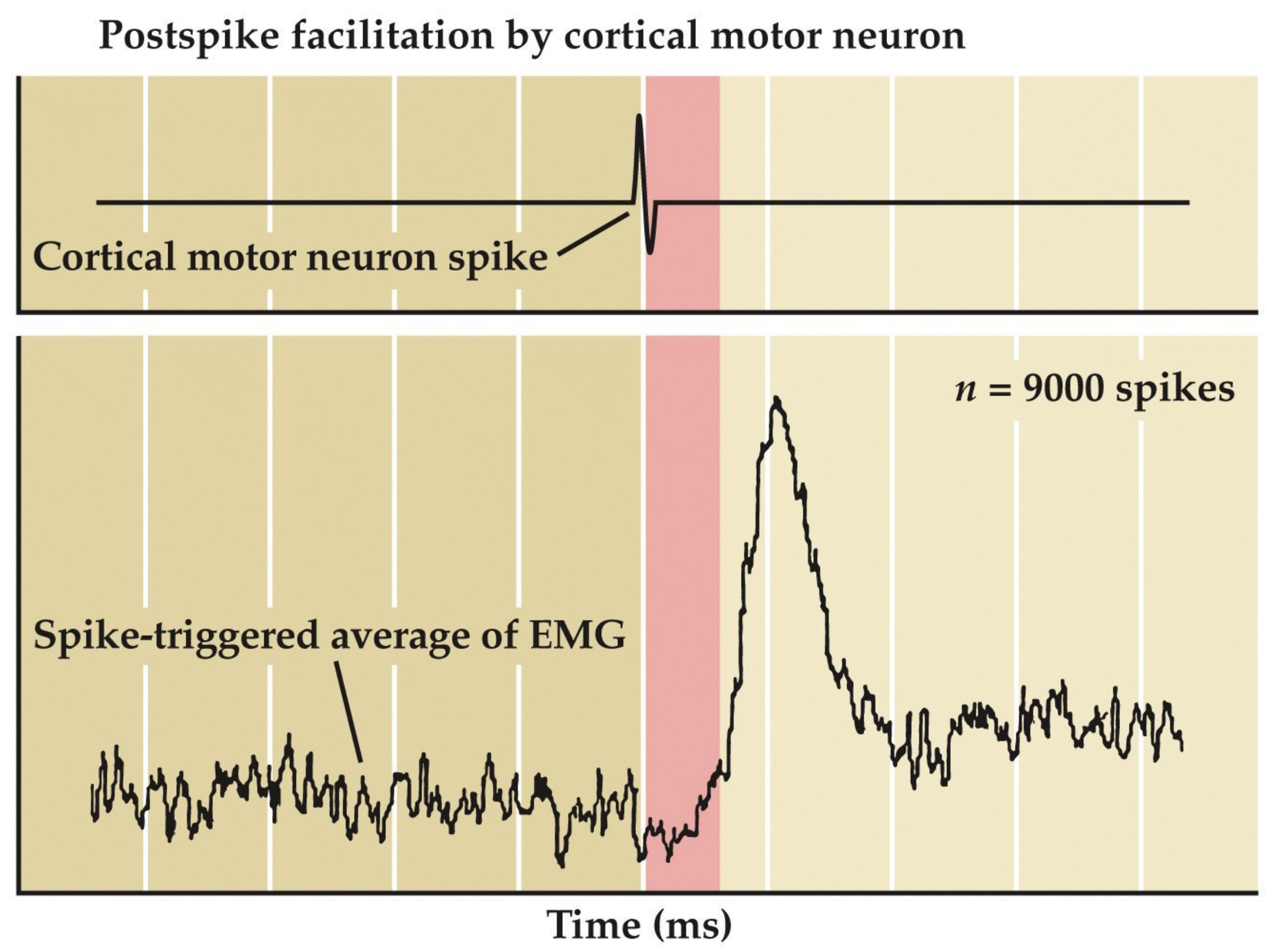
More complex maps (not just connected to id. motor pools) in cortex than appreciated by Penfield stimulation studies (Penfield and Boldrey *Brain* 1937). Woolsey 1958. Lemon TINS 1988

Movement encoding also applies to frontal eye fields for eye movements

Activity of single upper motor neurons is correlated with muscle movements



Neuroscience 5e Fig. 17.6



Neuroscience 5e Fig. 17.6. Porter and Lemon, 1993

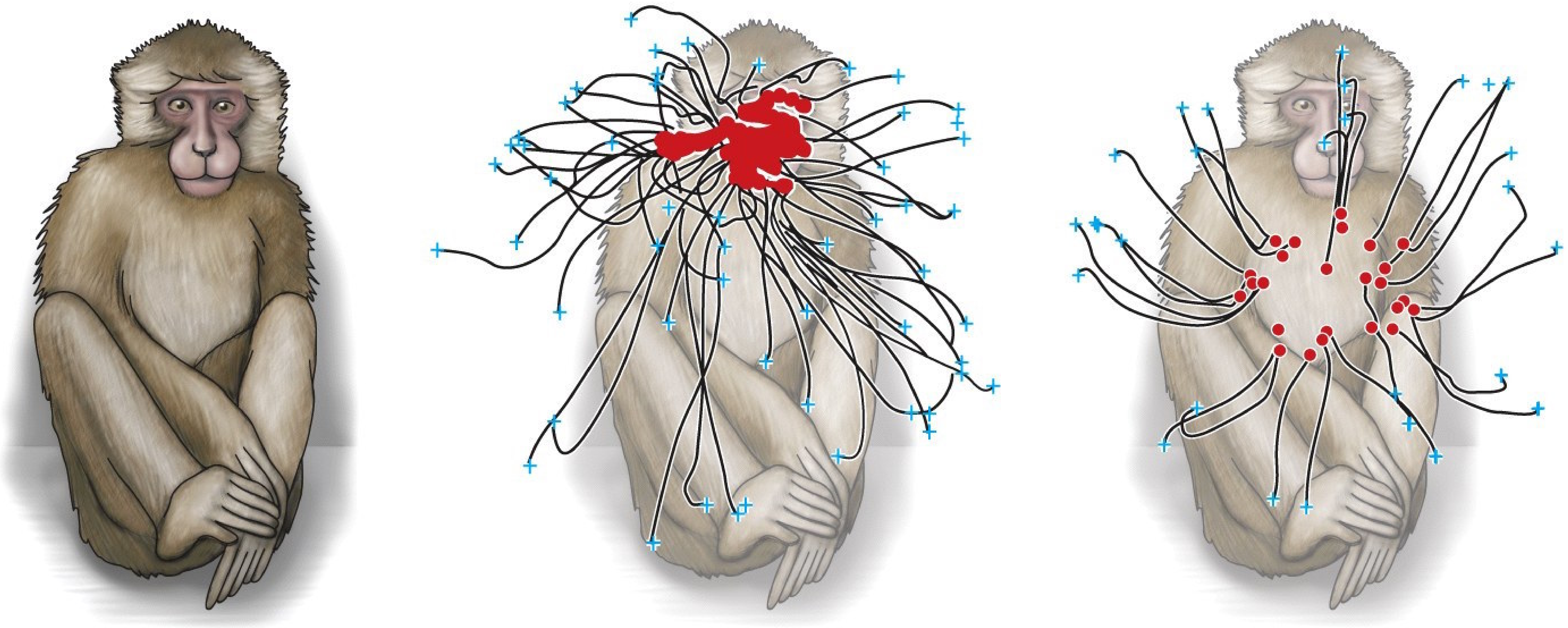
Speaker notes

left illustrates spike triggered averaging method for correlating muscle activity with the discharges of single upper motor neurons.

right shows the response of a thumb muscle by a fixed latency to the single spike discharge of a pyramidal tract neuron. This can be used to determine all muscles influenced by a given motor neuron.

Purposeful movements resulting from prolonged microstimulation of the primary motor cortex

Stimulation of limb movements. Blue crosses are start positions. Reds dots are final positions.



Neuroscience 5e Fig. 17.7. Graziano et al, 2005

Speaker notes

stimualtion that more roughly corresponds to volitional movements (hundreds of ms to sec), Graziano 2005. With these stimus, movements are sequentiall distrubted across mutliple joints and purposeful.

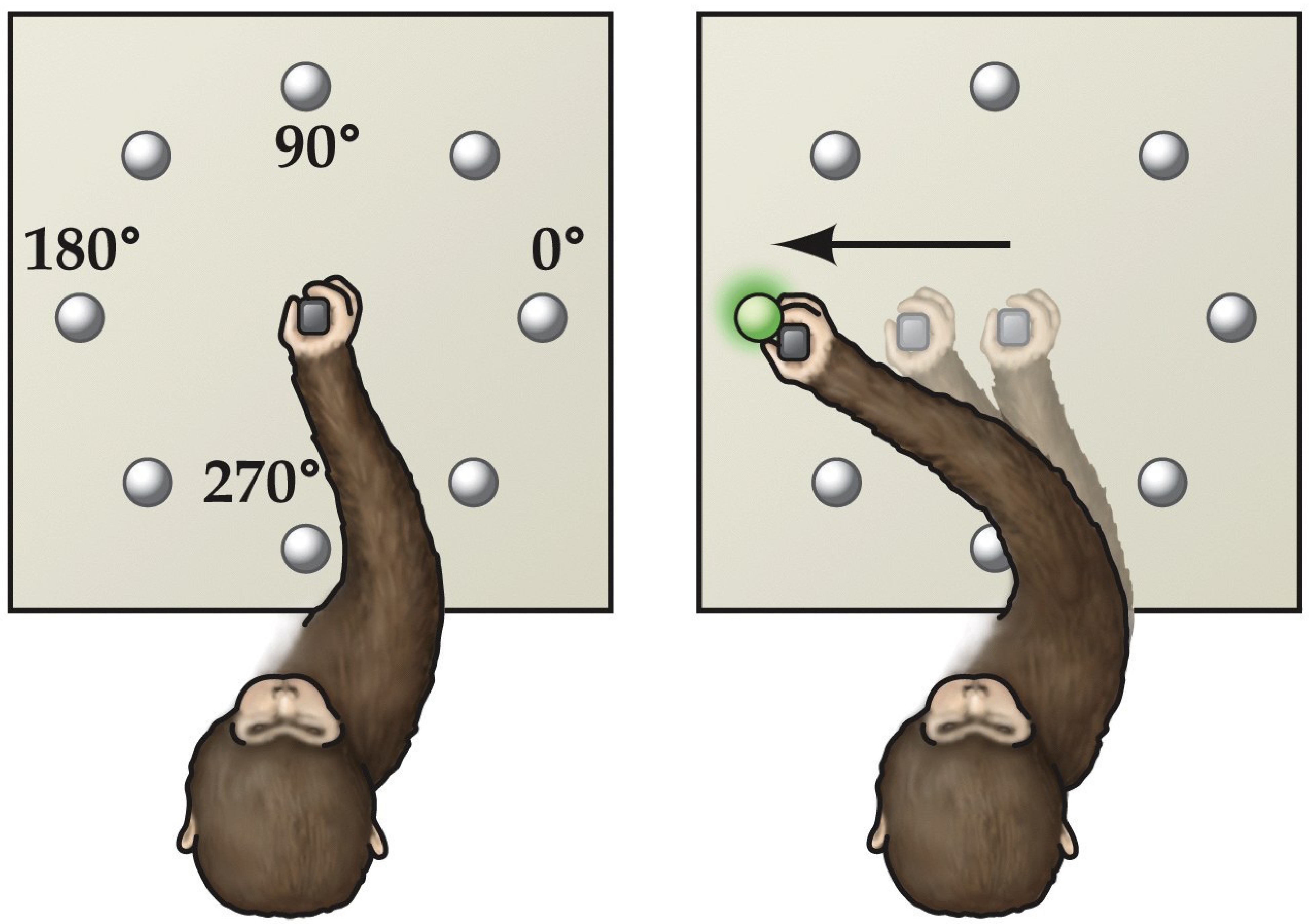
Coordinated movements of hand and mouth after stimulation near the middle of the precentral gyrus towards head (**like for eating**).

Coordinated movements of hand towards belly as if **inspecting an object**. Notice clustering of centralized trajectories after many trials instead of just random movements.

Blue crosses are start positions, curved black lines are final positions are reds dots.

Directional tuning of an upper motor neuron in the primary motor cortex

Monkey trained to move joystick in response to light



Neuroscience 5e Fig. 17.8, adapted from Georgeopoulos et al, 1986

Speaker notes

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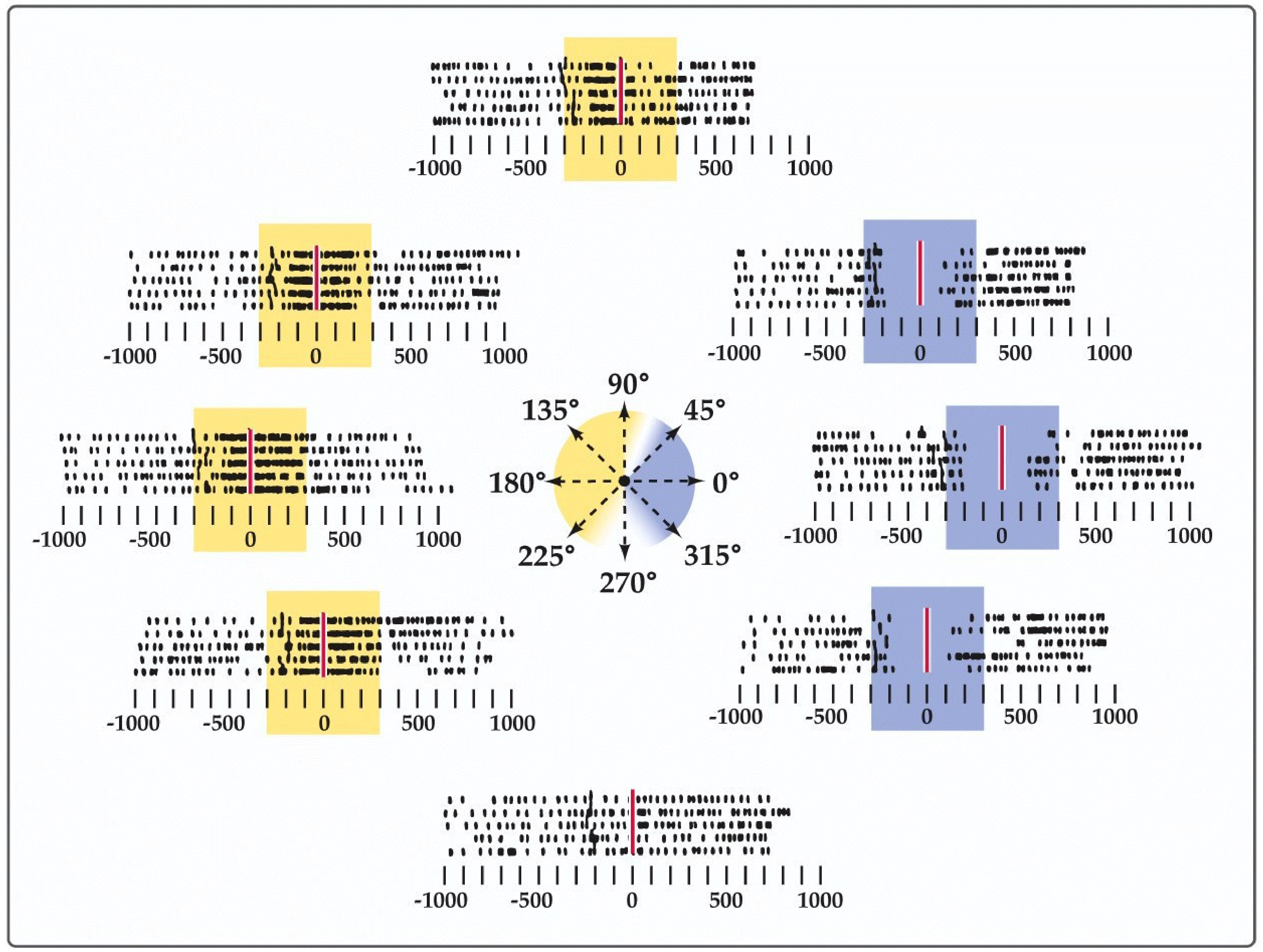
Directional tuning of an upper motor neuron in the primary motor cortex

Activity of a single neuron recorded in motor cortex is dependent on the direction of the future movement. Red line indicates movement onset, blac



Neuroscience 5e Fig. 17.8, adapted from Georgeopoulos et al, 1986<

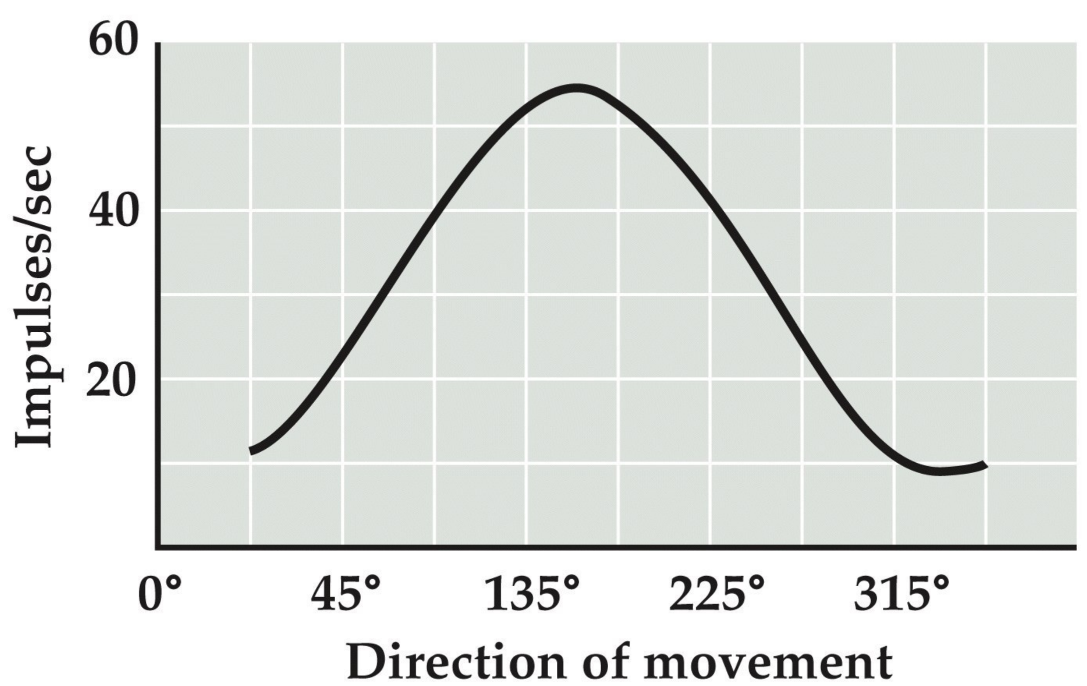
Speaker notes

raster plots, black dashes are individal spikes from one recorded neuron, 5 trials in each direction depicted
Notice that the neuron is broadly tuned to a wide range of angles

Directional tuning of an upper motor neuron in the primary motor cortex

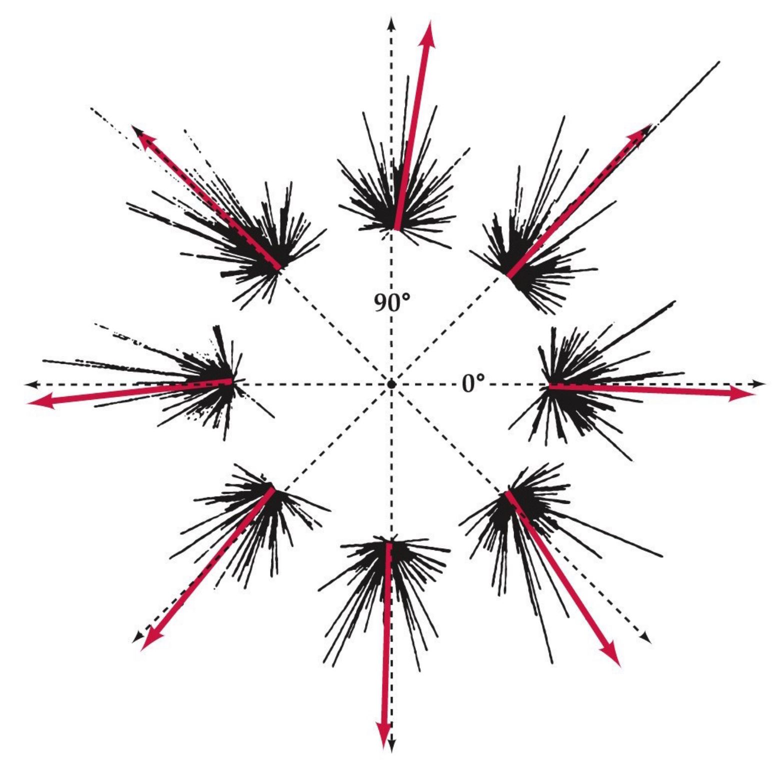
- Individual neurons are tuned too broadly to accurately predict direction of movement
- By comparing populations of neurons, one can calculate a direction
- Can use the activity of motor cortex to control robots

Directional, broad range tuning of cortical motor neurons



Neuroscience 5e Fig. 17.8

Population vector (red) for a population of simultaneously recorded upper motor neurons (black lines indicate each id. neuron's spike rate)



Neuroscience 5e Fig. 17.8, Georgeopoulos et al., 1986

Speaker notes

Summing response from a bunch of neurons shows that the direction is better encoded from an ensemble or population of neurons— so that different movement directions/sequences are represented by overlapping and distributed populations of neurons giving rise a series of neuronal population vectors rep all the different directions.

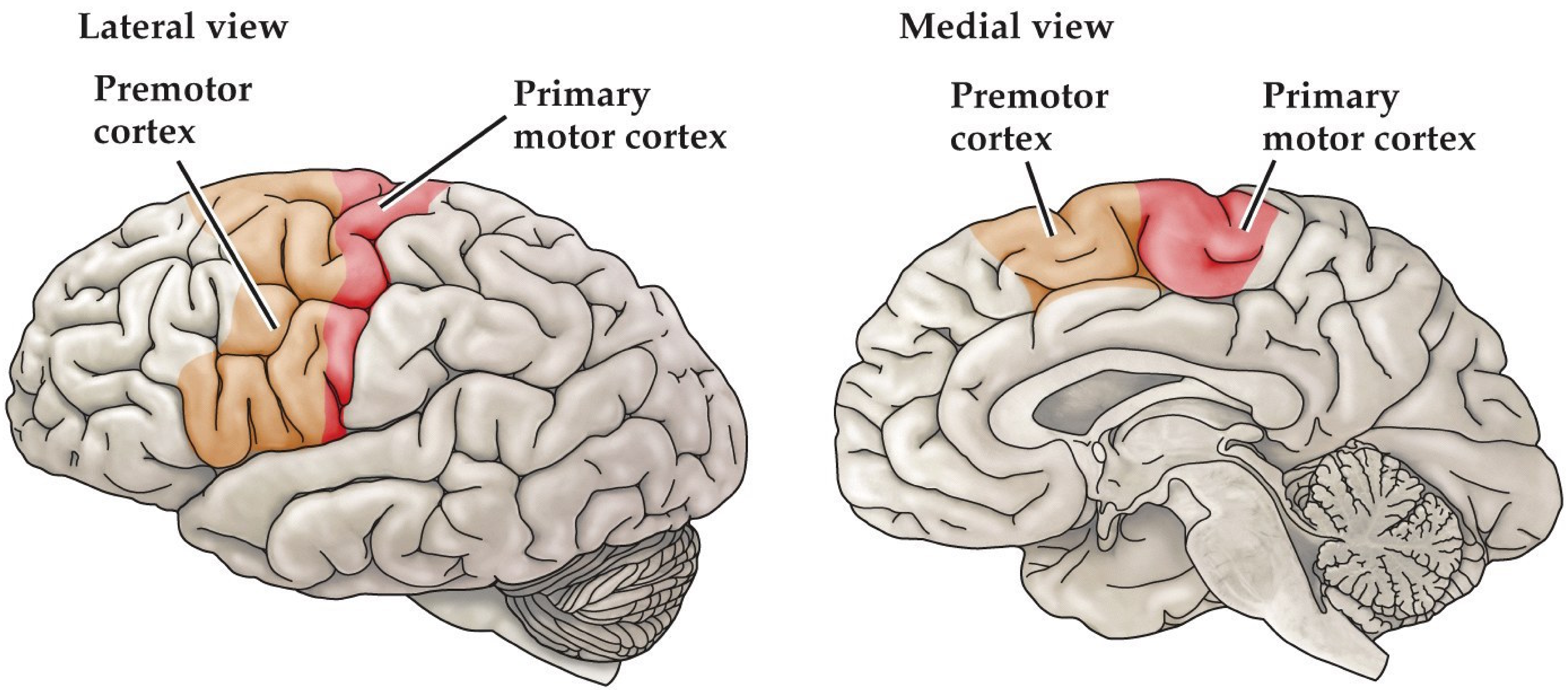
Controlling a robotic arm using motor cortex activity patterns in real time

Monkey brain machine interface

Speaker notes

TED talk by Miguel Nicolelis

Primary motor cortex and the premotor area in human

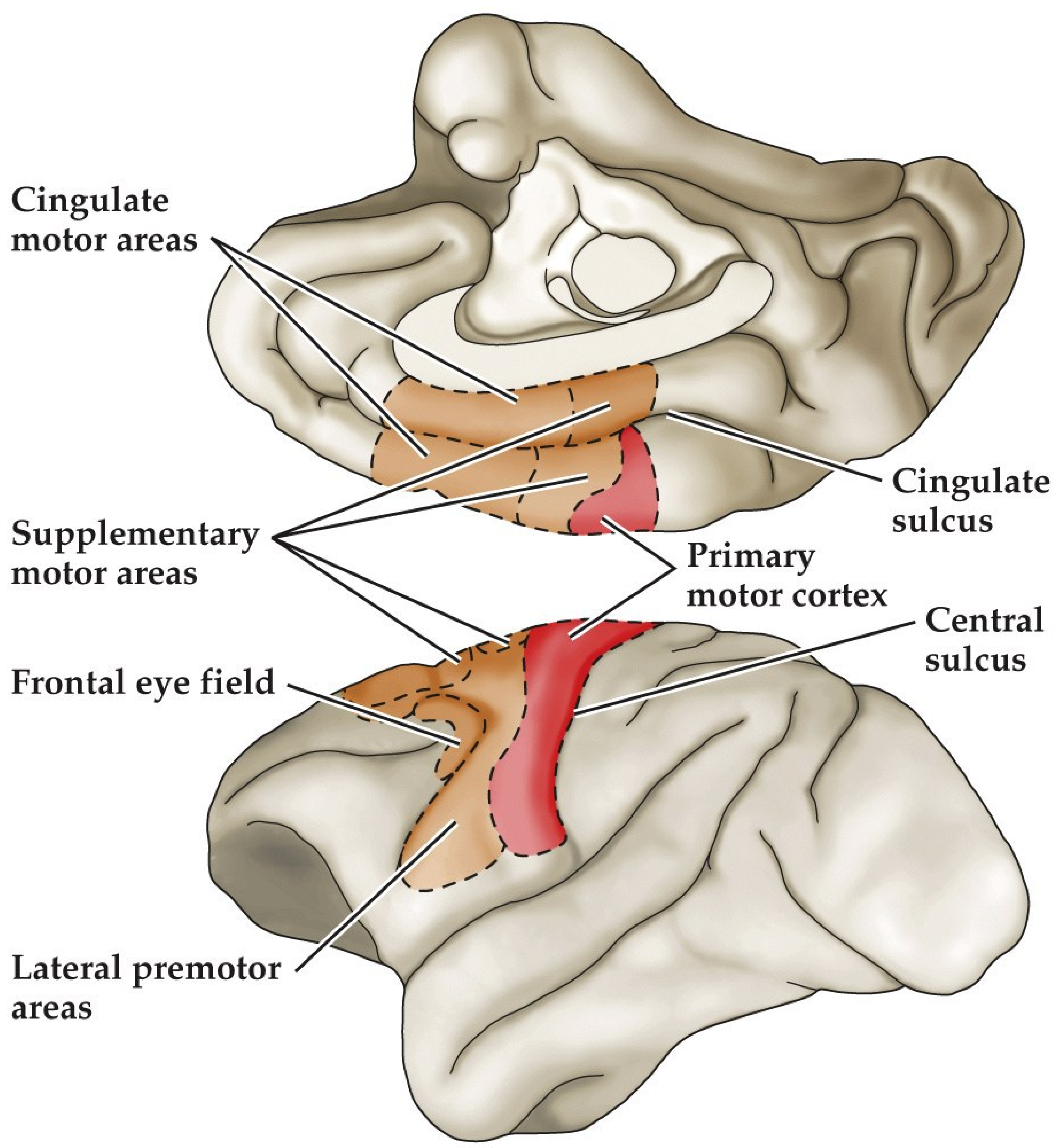


Neuroscience 5e Fig. 17.2

Speaker notes

lateral premotor and supplementary motor areas are involved in selecting and organizing purposeful movements of the limbs and face.

Primary motor cortex and the premotor area in macaque monkey



Neuroscience 5e Fig. 17.9

Speaker notes

Divisions of the motor cortex in the macaque monkey brain.

lateral premotor and supplementary motor areas are involved in selecting and organizing purposeful movements of the limbs and face.

the frontal eye fields organize voluntary gaze shifts. The cingulate motor areas are involved in expression of emotional somatic behavior.

The premotor cortex

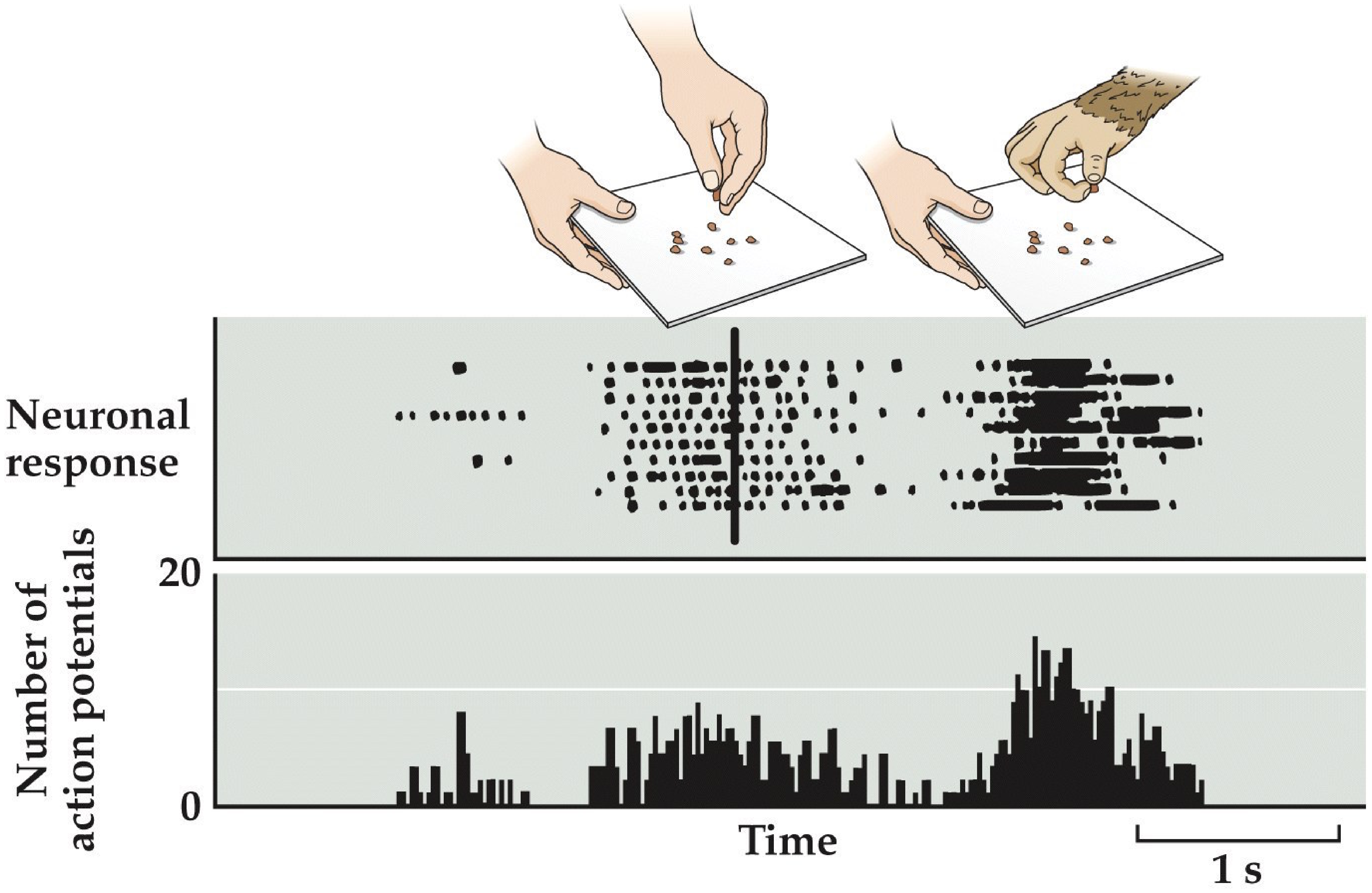
- Lies adjacent (rostral) to the primary motor cortex
- Makes extensive reciprocal connections with the primary motor cortex
- Projects directly to spinal cord (30% of axons in the corticospinal tract)
- Lateral premotor cortex- has neurons that are tuned to a particular direction of movement (like primary motor cortex) but differs in that they fire earlier than neurons in the primary motor cortex. This is especially important in conditional motor tasks, that pair a movement with a visual cue
- During the pairing of a visual cue with a motor task, the neurons will fire before any initiation of the task. This is used for intentions
- Lesions in monkey prevent vision conditioned tasks, although vision is fine and the task can be done in other ways

Speaker notes

thes neurons encode intention to perform a movement rather than just the movement itself.

Mirror motor neuron activity in lateral premotor cortex

Monkey mirror neuron for hand reaching is active while observing a human hand reach



Neuroscience 5e Fig. 17.10. Rizzolatti et al., 1996

≡

Speaker notes

A nice way to understand this is by examining portions of the lateral premotor cortex that contain so called mirror neurons that have been focus of a bit of attention over recent years.

peristimulus response histograms

passive observation of human hand interacting with (placing food on) tray and also during motor monkey's own movement to retrieve food

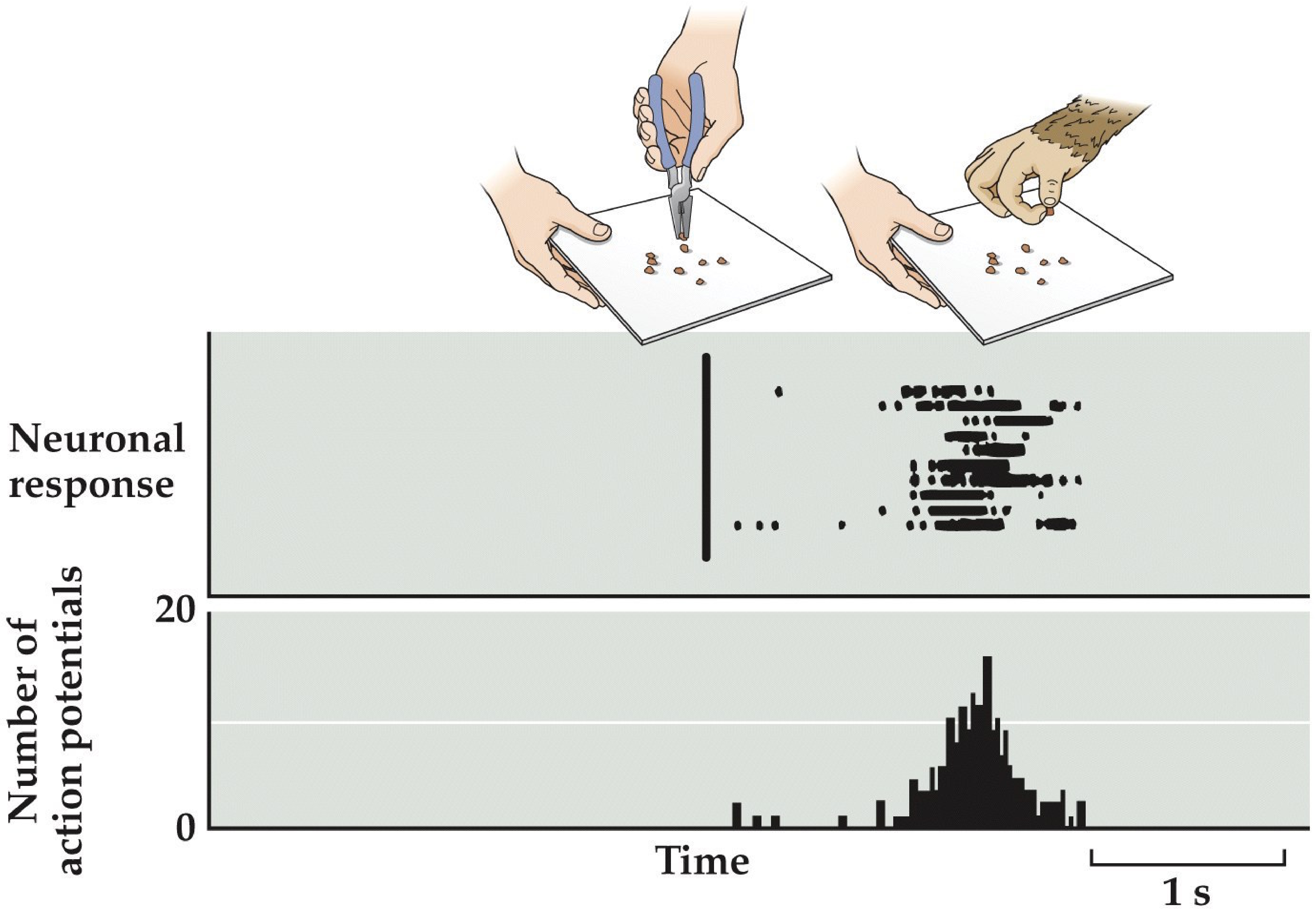
based on Giacomo Rizzolatti et al, 1996

https://www.youtube.com/watch?v=RuK2Y8JojN8

Found in two cortical areas-- the posterior part of the inferior frontal cortex and the anterior part of the inferior parietal lobule Rizzolatti:2004

Mirror motor neuron activity in lateral premotor cortex

Mirror neuron for hand reaching not active while observing pliers reaching



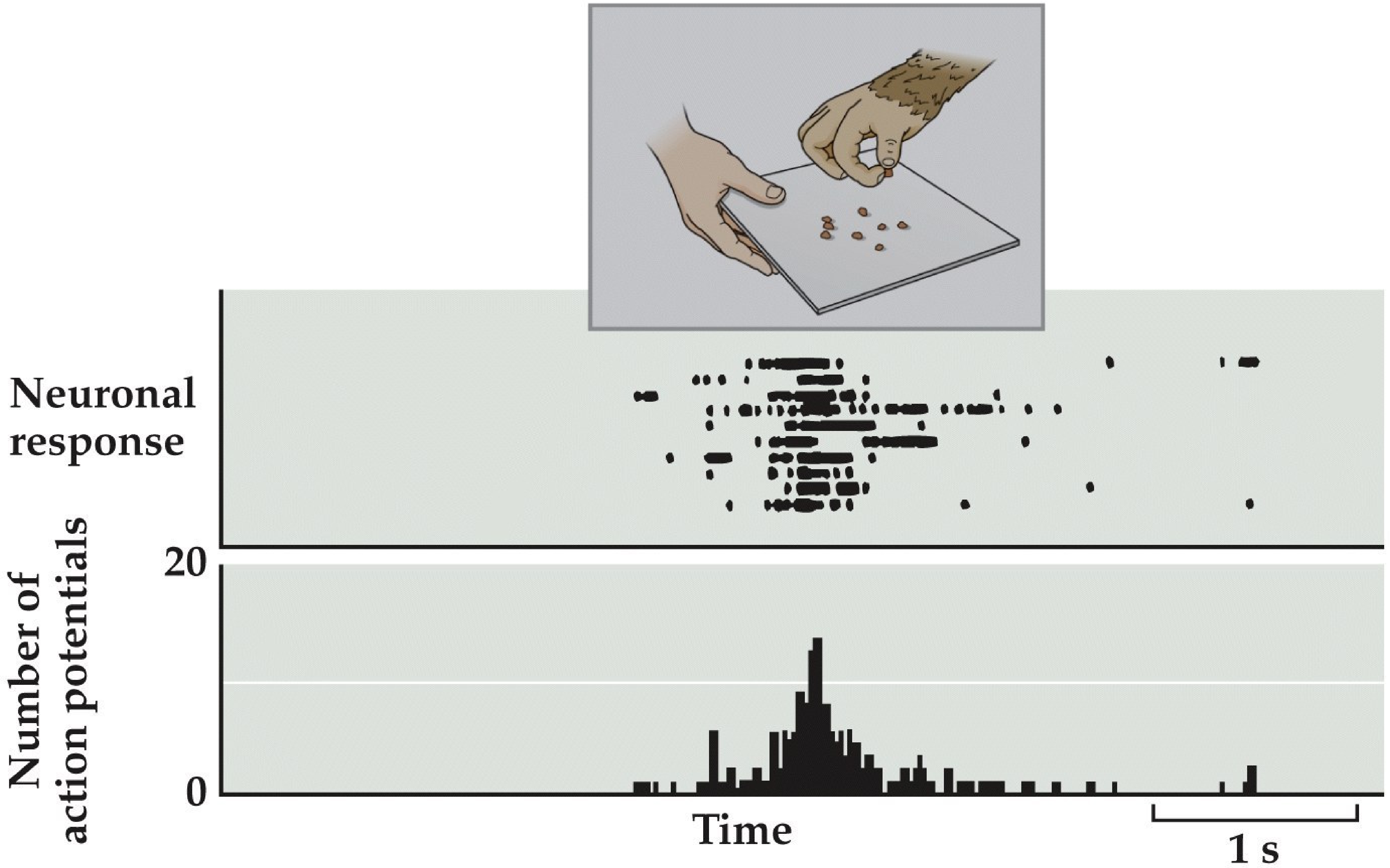
Neuroscience 5e Fig. 17.10. Rizzolatti et al., 1996

Speaker notes

does not respond when pliers are used to interact with food.

Mirror motor neuron activity in lateral premotor cortex

Mirror neuron for hand reaching active even when not observing self reaching



Neuroscience 5e Fig. 17.10. Rizzolatti et al., 1996

Speaker notes

Also fires when the behavior is executed behind a visual barrier.

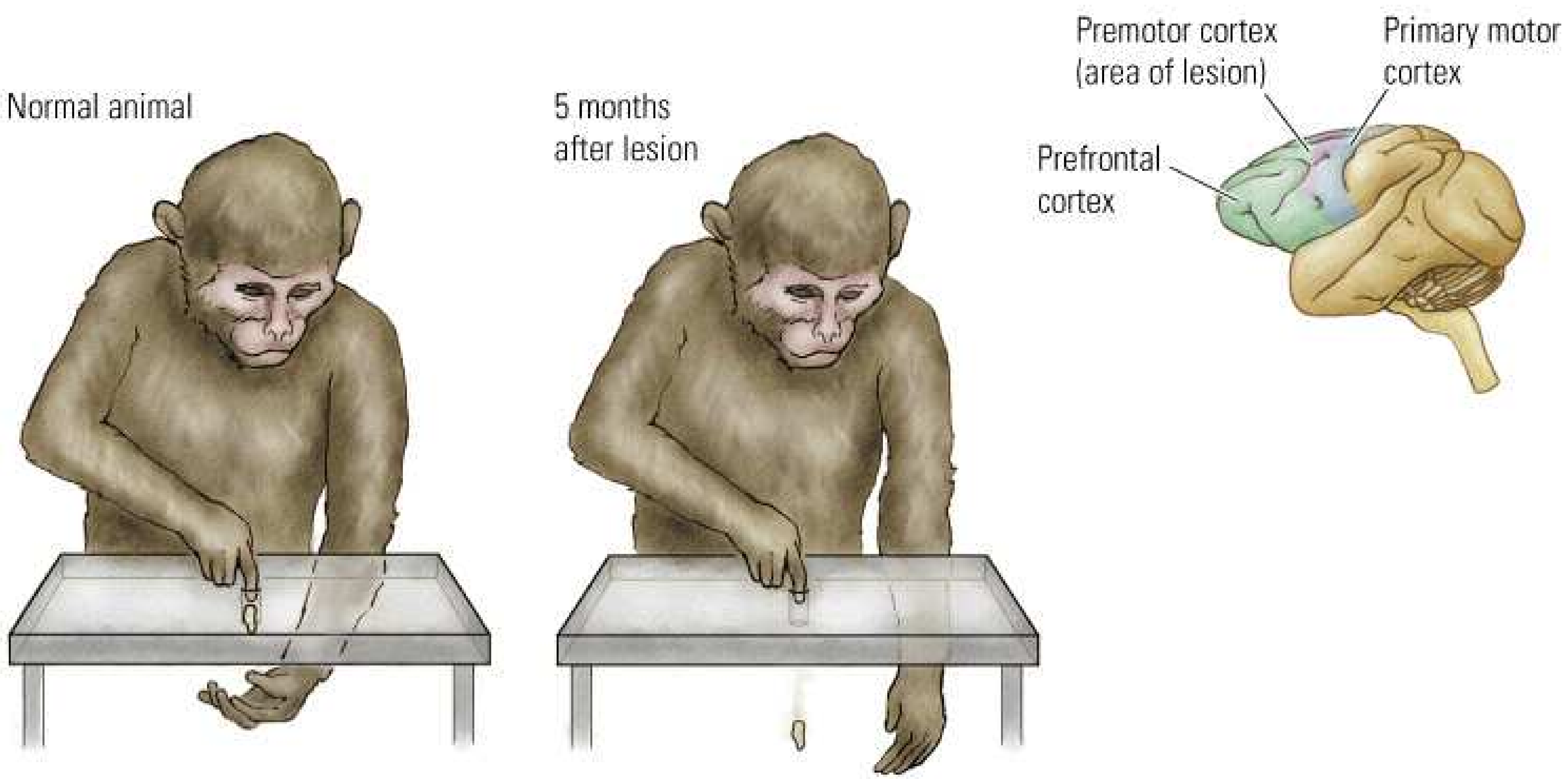
Suggests that parts of the premotor cortex play a role in encoding the actions of others.

Studies of this mirror neuron system is an active area of neurosci research and some hypotheses anticipate that this connections in the mirror neuron system could be disrupted in neurodevelopmental disorders such as autism or schizophrenia— but it is still important to note that these are active investigations and hypotheses still be tested.

http://nautil.us/blog/mirror-neurons-are-essential-but-not-in-the-way-you-think

Premotor cortex – two-hand coordination

- The monkey has learned the task: push the object through the hole and catch it with the other hand
- With damage to premotor cortex cannot coordinate two hands to do the task



Speaker notes

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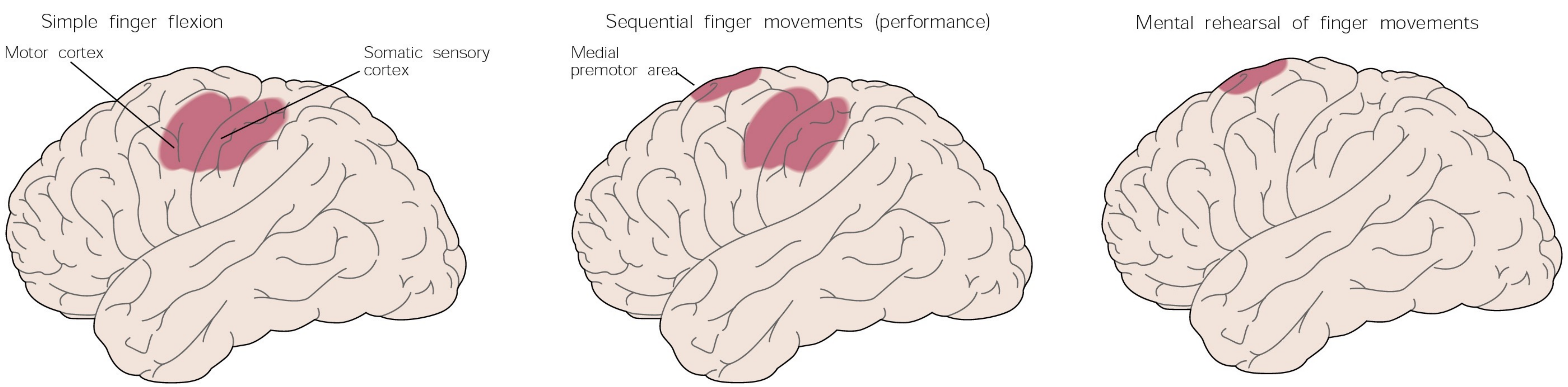
Medial premotor cortex

- Mediates the selection of movements
- Specified by internal rather than external cues
- Important for selecting movements based on memory, not in response to cues
- Cells will fire when just thinking about an event

Speaker notes

see also fig. 17.11 Neurosci 6e

Planning a movement sequence without moving activates supplemental motor area (medial premotor area)



Speaker notes

First neuroimaging data

todo: src

Effects of damage to the cerebral cortex

- By investigating patients with various types of brain damage we can see how the various components of motor performance may be affected. Examples:
  - Lesions to primary motor cortex (e.g. from a stroke) result in loss of voluntary movements on the contralateral (opposite) side of the body
  - Apraxia is the specific loss of the ability to plan and correctly perform co-ordinated motor skills, mainly as a result of damage to the supplementary motor area. Speech disorders result from damage to motor cortex
  - Patients can move muscles, and walk on command but can no longer link gestures to a coherent act, or to recognize the appropriate use of an object even though they can recognize what an object is

Speaker notes

Summary

- Motor
  - Output to muscles
  - Two main pathways:
    1. **Ventromedial system for balance, posture** and controlling head & eye movements. Important for muscles of legs & trunk needed for walking
    2. **Dorsolateral system for controlling movements of upper limbs** & extremities such as fingers and toes as well as movement of facial muscles
- Sensory
  - Input to primary somatosensory area
  - Two main pathways:
    1. **Dorsal spinothalamic tract for proprioception** (body awareness and position in space) and haptic feedback (sensation of fine touch and pressure)– crosses in medulla
    2. **Ventral spinothalamic tract for nociceptive** information– crosses over in spinal cord

Speaker notes

No notes on this slide.