<u>*COGS 17 section A02*</u>

vestibular, somatosensory, and motor systems

(for free??)

section resources repo

reminders

- **no section** next week (week 8) or the week after (week 9: memorial day) ‼
- midterm II is **this thursday**
  - same format as last midterm:
    - class time 3:30 - 4:50 PM
    - one shot; online; open notes
    - range: weeks 4-7
  - keep track of your pace!!!
- reminder: my office hours are **wednesdays 10:00 AM - 11:00 AM**
  - come over if you have any questions esp since finals are coming up!

vestibular system

movement and balance

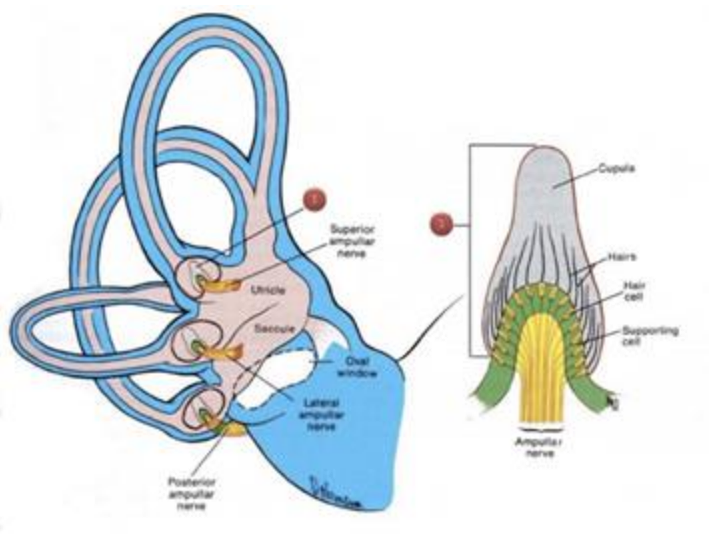
sensory mechanism of the vestibular system

vestibular organ = semicircular canals + otolith organs

- adjacent to cochlea in the inner ear

semicircular canals (angular acceleration eg. head rotation)

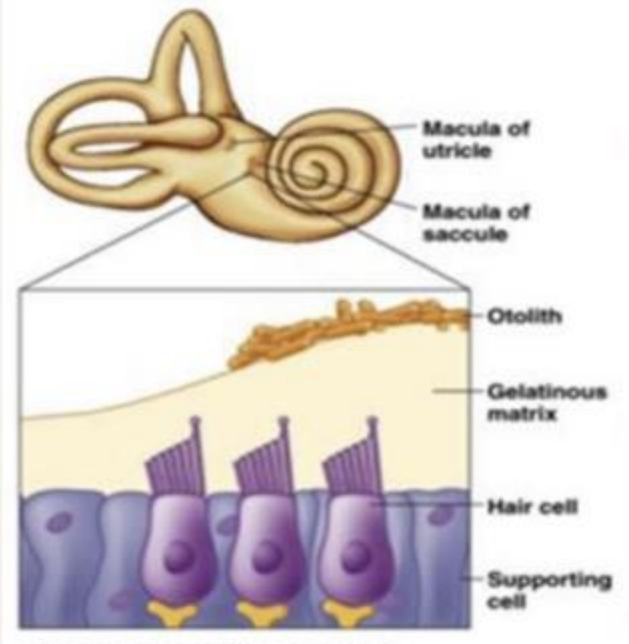
- 3 looped, fluid filled canals arranged in orthogonal planes (XY
- filled with K+ rich endolymph
- hair cells sit in cupula (jelly-like cap) in the ampulla at canal base
    - **crista ampullaris** = ridge of hair cell receptors
- mechanism for detecting angular acceleration
    - when head rotates → endolymph in ampulla lags behind (inertia)
    - when head stops moving → endolymph overshoots, deforming hair cells → alter NT release



sensory mechanism of the vestibular system

otolith (ear stone) organs (linear acceleration and tilt)

- vestibular sacs: utricle and saccule
  - **utricle**: contain hair cells on the floor
  - **saccule**: contain hair cells on the wall
- hair cells embedded in gelatinous otolithic membrane
  - **otoliths** (ear stones): dense calcium carbonate crystals on top of membrane
- mechanism for detecting linear acceleration and head tilts
  - gravity shifts otolith crystals → force exerted on gel layer bends hair cell cilia
    - direction of cilia bending determines hyperpolarization or depolarization of hair cell → alter NT release

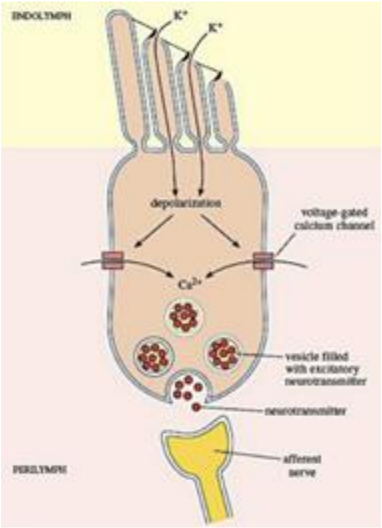


(a) Macula of an utricle or saccule

sensory mechanism of the vestibular system

hair cell transduction dynamics

- K+ goes in → NT released
- spontaneous firing in absence of input (head is still or in constant velocity)
  - no rotation: hair cells release a *base rate* of NT
  - hair cell cilia bent to longer side → K+ channels open (depolarization)→ more NT release
  - hair cell cilia bent to shorter side → K+ channels close (hyperpolarization) → less NT release



key takeaway: vestibular system only detects ***changes*** in velocity and orientation, not steady movement!

vestibular pathway

hair cells in semicircular canals and otolith organs

- NT release synapses onto…

vestibular ganglion cells

- axons form part of 8th cranial nerve that then connect to…

vestibular nuclei in the medulla

- main processing center for vestibular information
- generating nausea (motion sickness)
- that project to…
  - spinal cord + brainstem (posture)
  - superior colliculus (visually processing movements)
  - cranial nerves 3,4,6 (eye muscle movements)

cerebellum

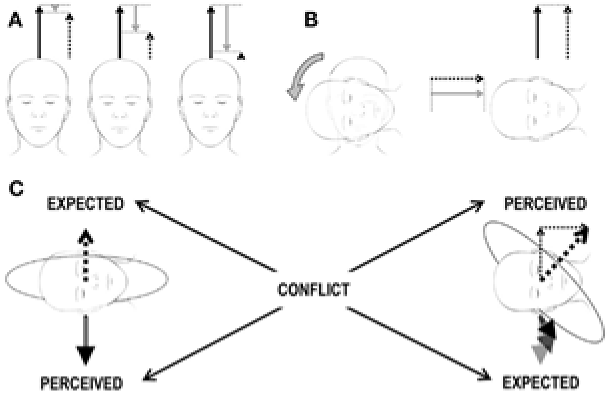
- balance control during movement

** higher pathways beyond are less understood – possibly temporal lobe (?)*

motion sickness

occurs due to mismatch of sensory information

- visual, motor, and vestibular inputs aren't coordinating with one another
- creates confusion in the brain's integration centers (vestibular nuclei of medulla)
    - brain expects certain sensory feedback patterns when you move
        - mismatched vestibular info → brain interprets as a sensory disturbance similar to from toxins → induce nausea as protective mechanism



in moving car

- you're not moving but your eyes see environment moving past you
    - vestibular doesn't detect change but eyes are detecting change

spinning then stopping

- after spinning, endolymph continues to move but visual scene is now stable
    - eyes aren't detecting change but vestibular detects change

somatosensory system

detecting sensory information

somatosensory receptors

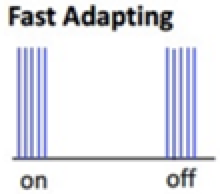
free nerve endings: unmyelinated/lightly myelinated, found on skin, mucus membranes, around hair follicles

- thermoreceptors: temperature change
- nociceptors: pain and itch
- follicle receptors: subtle stimuli on skin

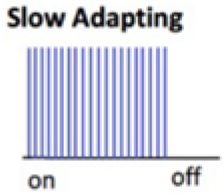
mechanoreceptors: various types of touch and proprioception (internal movement)

mechanoreceptor	**receptive field**	**adaptation speed**	**function**
meissner's	small	fast	rapid changes eg. slippage
merkel's	small	slow	detail discrimination eg. Braille reading
pacinians	large	fast	large-scale movement eg. limb bending
ruffini	large	slow	sustained stretch or pressure eg. sitting

fast adapting: stimulus onset/offset, not during sustained stimulation



slow adapting: continue firing as long as stimulus is present



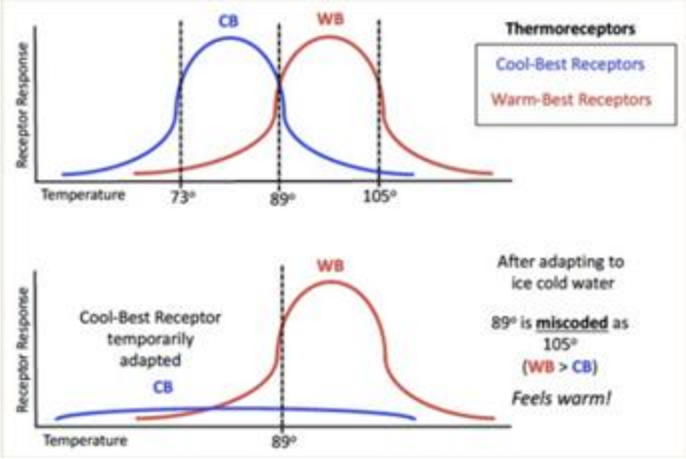
across fiber coding: selective adaptation in temperature receptors

free nerve endings

- warm best (**WB**) receptors: temperatures warmer than skin (~89F/32C)
- cool best (**CB**) receptors: temperatures cooler than skin
- overlap in temperature sensitivity → both receptors can be active simultaneously
  - temperature not encoded by any one receptor alone, but by the pattern of activation across multiple receptor types

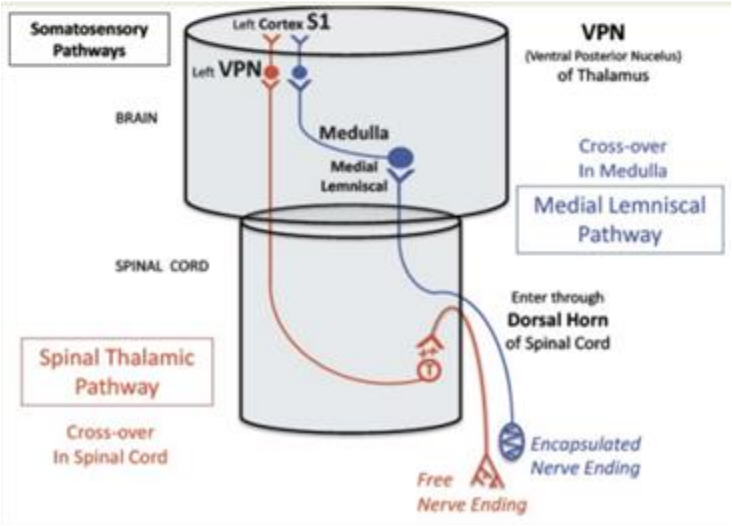
brain interprets temperature based on relative activity of WB and CB receptors

- physiological zero: 89F (32C) : WB = CB (equal firing)
- selective adaptation placing hand in ice water
  - adapts CB receptors → response weakens
    - place hand in neutral water → WB > CB
      - brain interprets water warmer than it really is



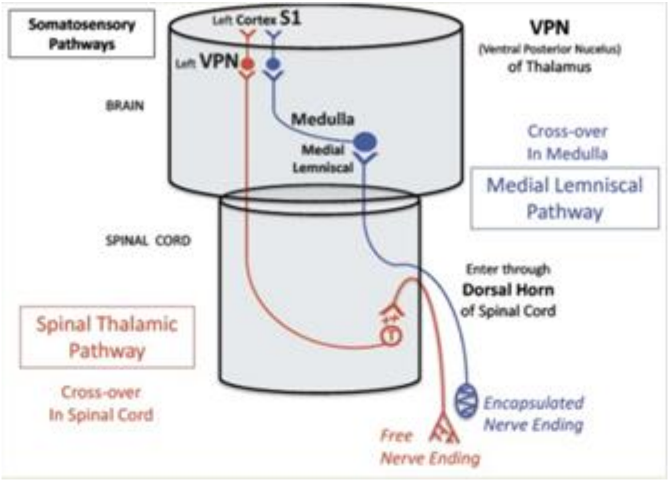
somatosensory pathways: spinothalamic pathway

1. ***free nerve endings*** detect pain temperature and itch
2. axons enter ipsilateral dorsal root of spinal cord
   a. synapse on second-order neurons
   b. reflex circuits
3. second-order neurons cross over to contralateral side in spinal cord
4. info ascend to contralateral ventral posterior nucleus (**VPN**) of thalamus
5. somatosensory cortex



somatosensory pathways: medial lemniscal pathway

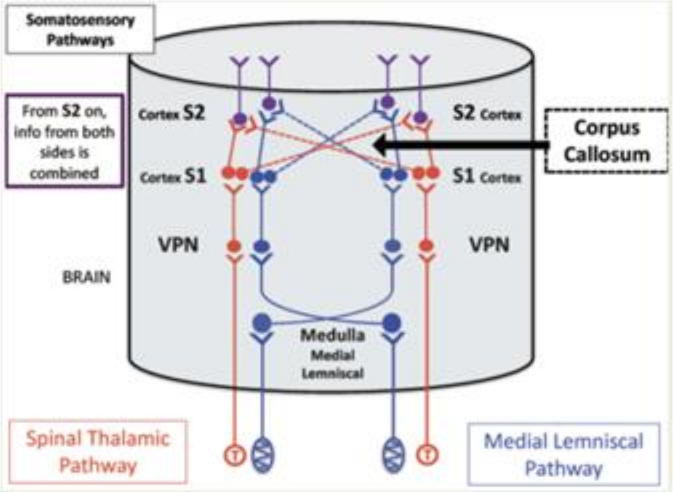
1. ***encapsulated receptors*** detect touch and proprioception
2. axons enter ipsilateral dorsal root of spinal cord
   a. main axon does NOT synapse as it ascends
3. first synapse: ipsilateral medulla
   a. second order neurons cross over in brainstem
4. info ascend and synapse in contralateral VPN
5. final projection to somatosensory cortex



somatosensory cortex

both pathways

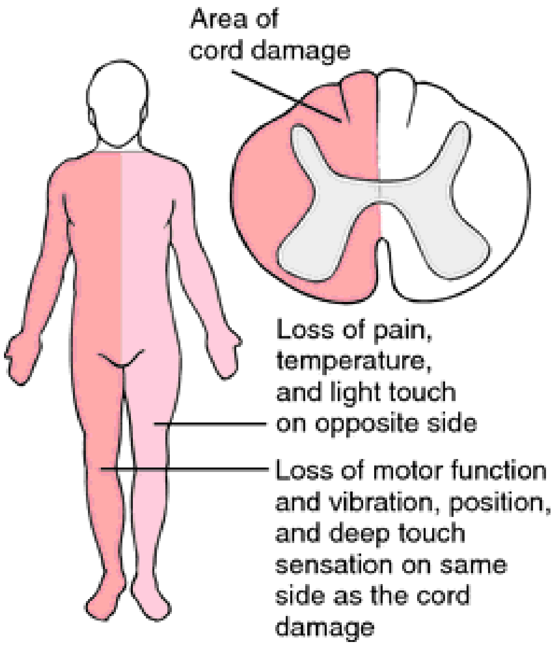
- first synapse at crossover point (spinal cord or medulla)
- ascend to contralateral VPN
- signals continue to primary somatosensory cortex (S1) → S2
  - parietal lobe
- corpus callosum for interhemispheric sharing
  - S2 integrates input from both sides



brown sequard syndrome

damage to only on side of spinal column

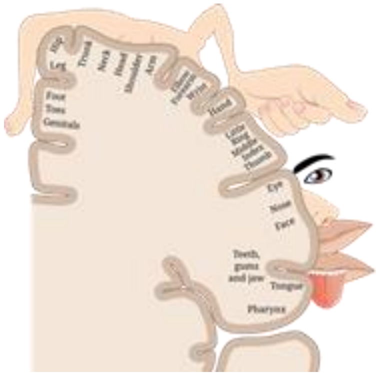
- crossover points in somatosensory pathways determine symptom patterns
- different sensory deficits on opposite sides of the body
  - reduced/loss of touch and position on ipsilateral side
    - medial lemniscal crosses in medulla
  - reduced/loss of temperature and pain perception on contralateral side
    - spinothalamic crosses in spinal cord



somatosensory cortex organization

in postcentral gyrus of parietal lobe

- cortex contains topological maps of the body surface (penfield map or “homunculus)
    - each body part represented in proportion to its *sensory resolution* (not physical size)!
    - separate maps for touch, proprioception, temperature, pain
- magnification factor
    - areas with small receptive fields and dense high-acuity receptors are overrepresented in cortex
        - take up disproportionately large portion of map



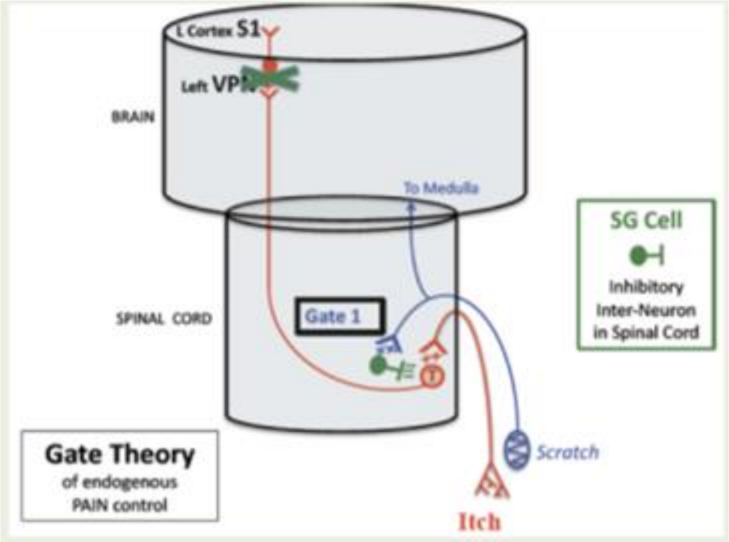
gate theory

basic pain signal pathway

- nociceptors release **substance P** in spinal cord → **T cells** activated → pain signal up to brain
- pain perception depends on whether T cell activity is turned on or off (gate open or closed)

mechanism 1: local touch inhibition → close gate via body feedback

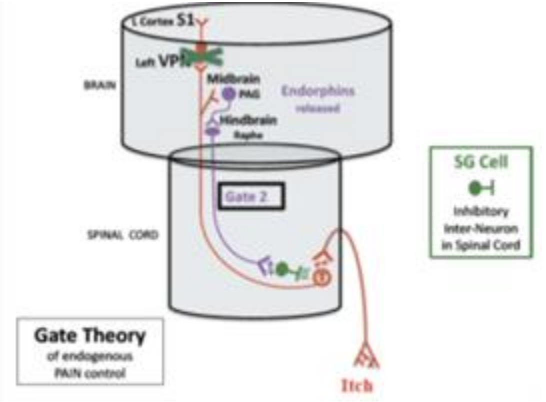
- touch receptors near site of pain send collateral signals to spinal cord
- activate inhibitory interneurons (**SG cells**)
    - T cells inhibited → reduce response to substance P
        - "gate" closes; pain signal reduced/blocked



gate theory

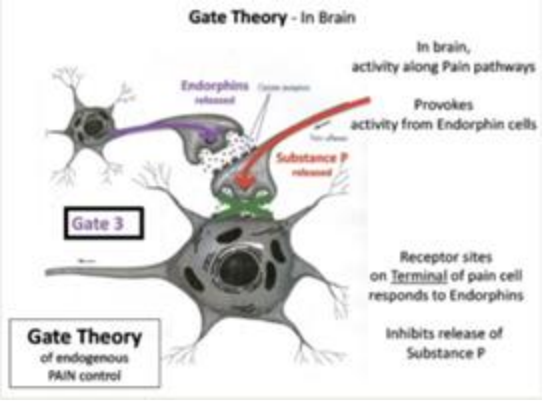
mechanism 2: brainstem inhibition → endorphin pathway

- **periaqueductal gray** (PAG) in midbrain releases endorphins (natural painkillers)
  - *inhibits* inhibitory cells in raphe → raphe activated → sends excitatory signals to spinal cord
    - SG cells activated to inhibit T cells → gate closes



mechanism 3: brain-level inhibition → **axoaxonal** relationships

- substance P-releasing neurons have endorphin receptor sites on axon terminals
  - releasing endorphins inhibit substance P release via axo-axonal connections (other cells synapse onto these receptors)
    - pain signal reduced before reaching postsynaptic target



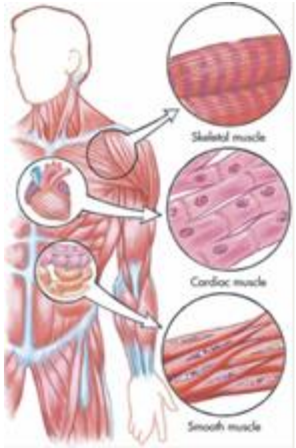
movement

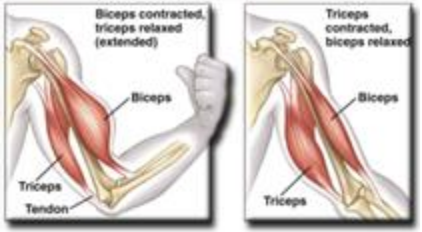
yes

muscles

3 muscle types

- **smooth** – internal organs (involuntary)
- **cardiac** – heart (endogenous rhythm)
- **striate** – skeletal and facial (voluntary)
  - parallel fibers; attached to bones by tendons
  - work in antagonistic pairs
    - flexor (moves bone *toward* body)
    - extensor (moves bone *away*)
  - **neuromuscular junction**
    - motor neurons exit ventral root of spinal cord, synapsing directly onto muscle → release **acetylcholine** (ACh)
    - muscle fibers fire *action potentials* (all or nothing)





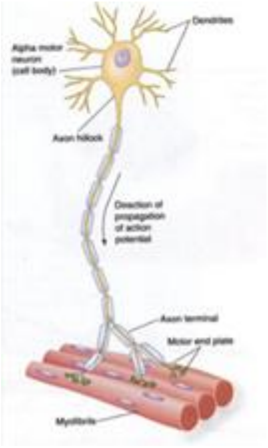
contractile mechanism

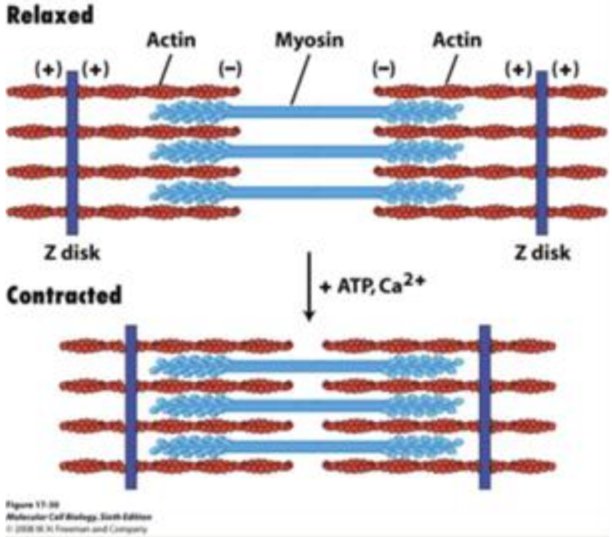
sarcomeres: functional unit of muscle contraction

- each muscle fiber contains chain of repeating **sarcomeres** (basic contractile unit)
    - components
        - **myosin**: thick filament with cross-bridges; responsible for generating force
        - **actin**: thin, coiled double-stranded filament anchored to the sarcomere

contraction mechanism

- when Ca++ enters muscle cells, sarcomeres are activated
- myosin cross bridges hook into coiled actin
    - cross bridges bend to tighten actin coil → relax and muscle passively stretches back





types of spinal reflexes

stretch reflex

- muscle spindles detect passive stretch (e.g. knee tap)
- sends signal to spinal cord → directly excites motor neuron
- monosynaptic: sensory neuron → motor neuron → same muscle contracts

golgi tendon reflex

- golgi tendon organs detect excessive contraction
- activates inhibitory interneurons → motor neuron suppressed
- also engages antagonistic pair (e.g. excites extensor if flexor inhibited)

types of spinal reflexes

pain withdrawal reflex

- nociceptors activate interneurons in spinal cord
- excite flexor motor neurons → rapid withdrawal
- reflex occurs before pain reaches brain

scratch reflex

- oscillator circuit (e.g. rhythmic scratching)
- controlled by central pattern generators in spinal cord, cerebellum
- rate is fixed, persists even without brain input

infant reflexes

- rooting: touch cheek → turn & suck
- grasping: touch palm → grip (briefly weight-bearing)
- vestigial from primate ancestors; can reappear in brain damage

motor pathway: corticospinal

for control of voluntary motion on contralateral side of body

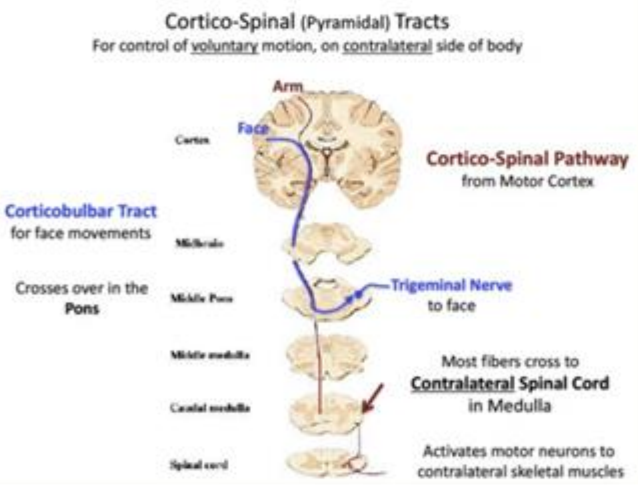
- originate in large **pyramidal cells** in motor cortex
- cross over at the pyramids of medulla then project to contralateral spinal cord, synapsing on interneurons or motor neurons in spinal cord
- some fibers first synapse in red nucleus (integrates vestibular + cerebellar input)

function

- fast, myelinated tracts for precise voluntary movement
- especially important for distal limbs, hands, fingers, and facial muscles

corticobulbar tract for facial control

- fibers to face cross in the pons
- synapse on cranial motor neurons (trigeminal nerve)



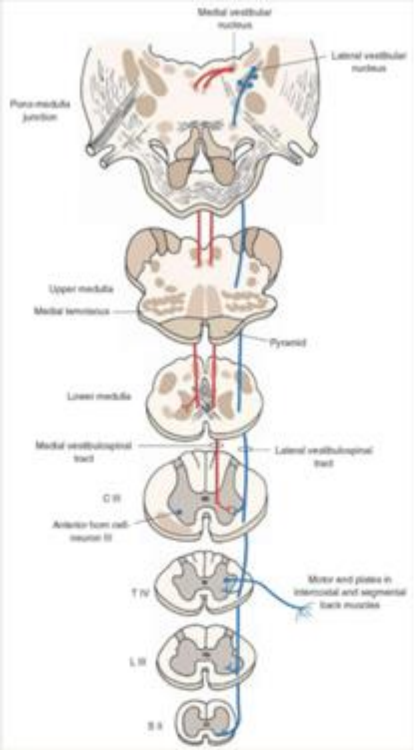
motor pathway: ventromedial

functions

- controls bilateral, midline body movements
- coordinates neck, shoulders, trunk, and proximal limbs
- involved in posture, balance, and gross motor actions (e.g. walking)
- supports sensory-motor integration, like head-eye coordination

pathway/structure

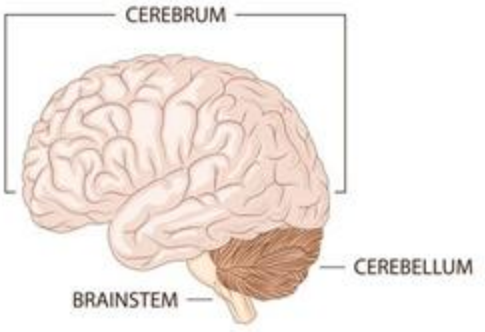
- composed of multiple sub-pathways from subcortical areas
- many fibers pass through the tectum, vestibular nuclei, and reticular formation
  - most synapse on spinal interneurons
- projections are primarily ipsilateral



cerebellum (little brain)

about 13% of brain mass, but contains ~50 billion neurons (more than rest of brain combined)

- supports rapid, coordinated, and ballistic movements
- creates and manages motor programs (pre-learned, precise movement sequences)
    - saccades – ballistic eye movements (cannot be altered mid-flight)
    - learned behaviors – clapping, sports, manual skills
    - timing tasks – movement prediction, auditory intervals, attention shifts
- operates largely without conscious control, using ongoing sensorimotor feedback



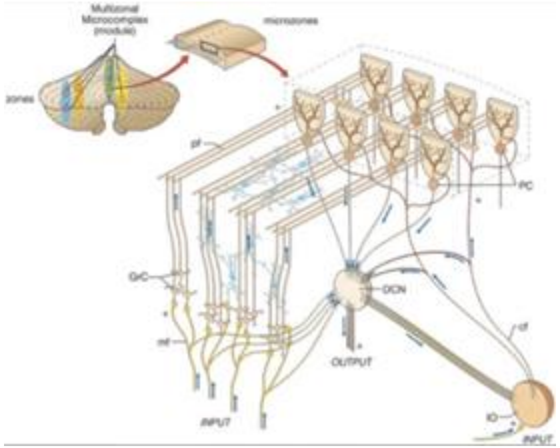
cerebellum (little brain)

inputs and outputs

- proprioceptive input from spinal cord & visual and vestibular info via cranial nerves
- cortical input about planned and initiated movements → calculates precise muscle output adjustments
- projects to all major motor structures, esp ventrolateral nucleus (**VLN**) of thalamus
- no direct connection to motor neurons, but modulates motor commands sent to spinal cord

circuitry

- parallel fibers run across rows of **purkinje cells** (like telephone poles)
    - excitation: purkinje sends inhibitory signals to deep nuclei
    - communicate to deep nuclei activate motor nuclei in brain
    - timing coded by distance along parallel fibers



basal ganglia: organizes activity in tasks

key structures

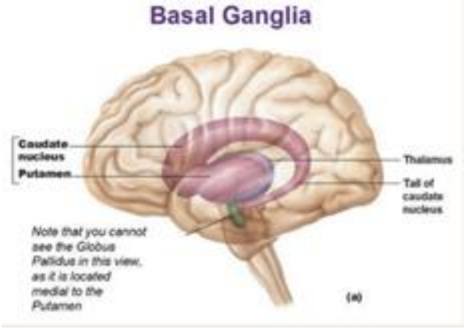
- input: caudate nucleus + putamen = **striatum**
  - from thalamus, tegmentum, cortex
- output: **globus pallidus**
  - up motor cortex via thalamus
  - down red nucleus, cerebellum, spinal cord
- claustrum connects frontal and sensory cortex

functional role

- cycles information in a **re-entrant loop** (cortex→basal ganglia→cortex)
- task-based, learned sequences of behavior
- slow smooth voluntary movements (posture, walking)
- habit formation, motor program selection, automated behavior

clinical links

- **parkinson's disease**: motor deficits from dopamine loss
- OCD: overactive loops → repetitive, unsatisfying behavior
- ADD: disrupted circuits → poor task focus
- connected to amygdala (emotion) and nucleus



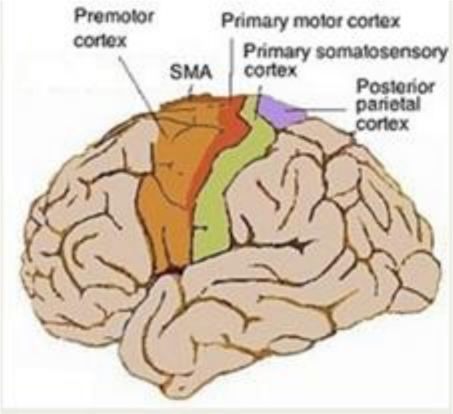
motor cortex

primary motor cortex (M1)

- frontal lobe on precentral gyrus; contains motor homunculus (topological map)
- receives input from somatosensory cortex
- no direct muscle connection!! sends commands to motor neurons in brainstem & spinal cord

secondary motor cortex – movement planning; connects with visuo-spatial areas of parietal cortex

- **premotor cortex**
    - movement preparation
    - part of the mirror cell system – responds to seeing own or others' actions
    - includes broca's area for speech production
- supplementary cortex
    - preparing complex or rapid movement sequences



kahoot