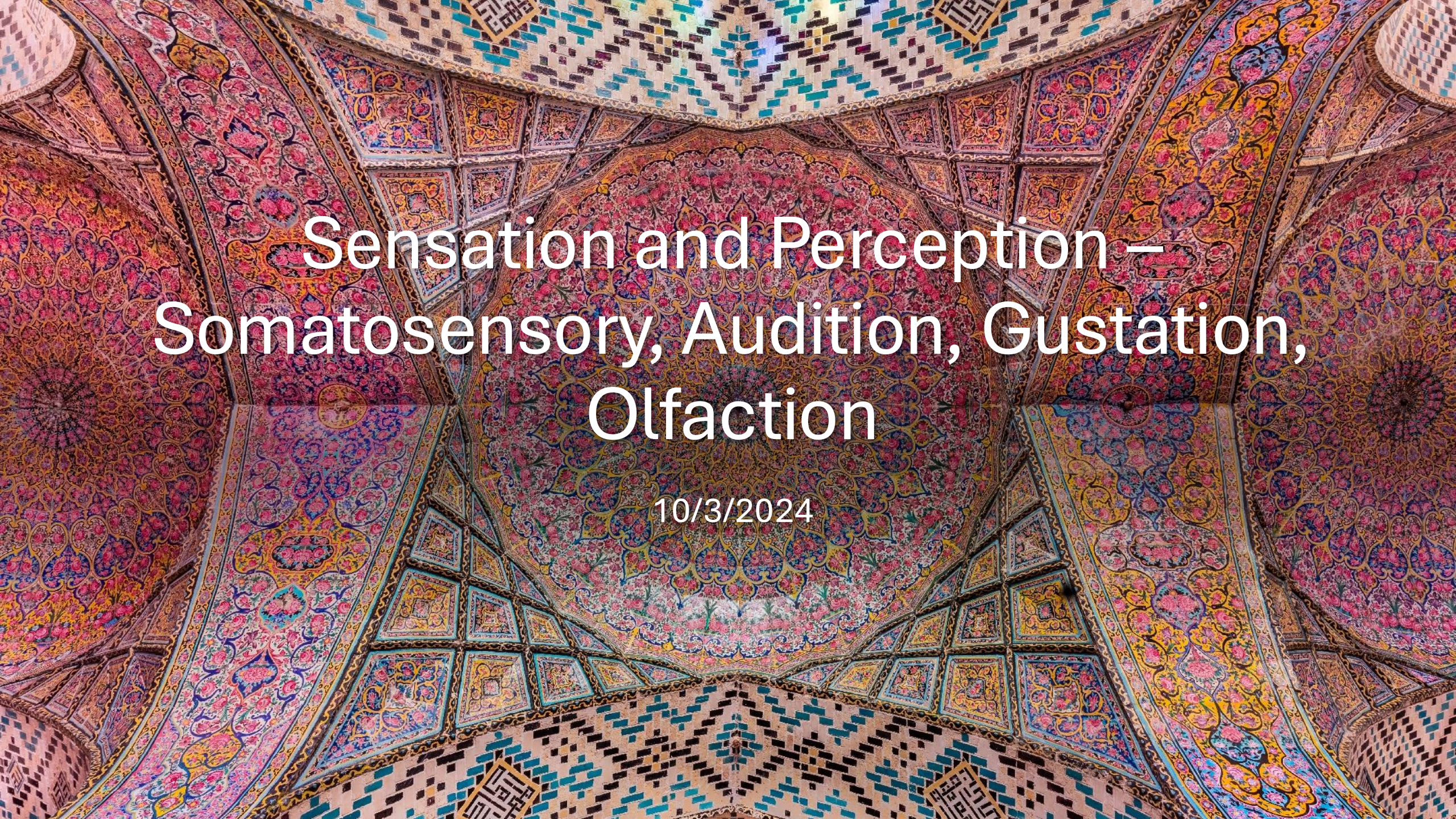
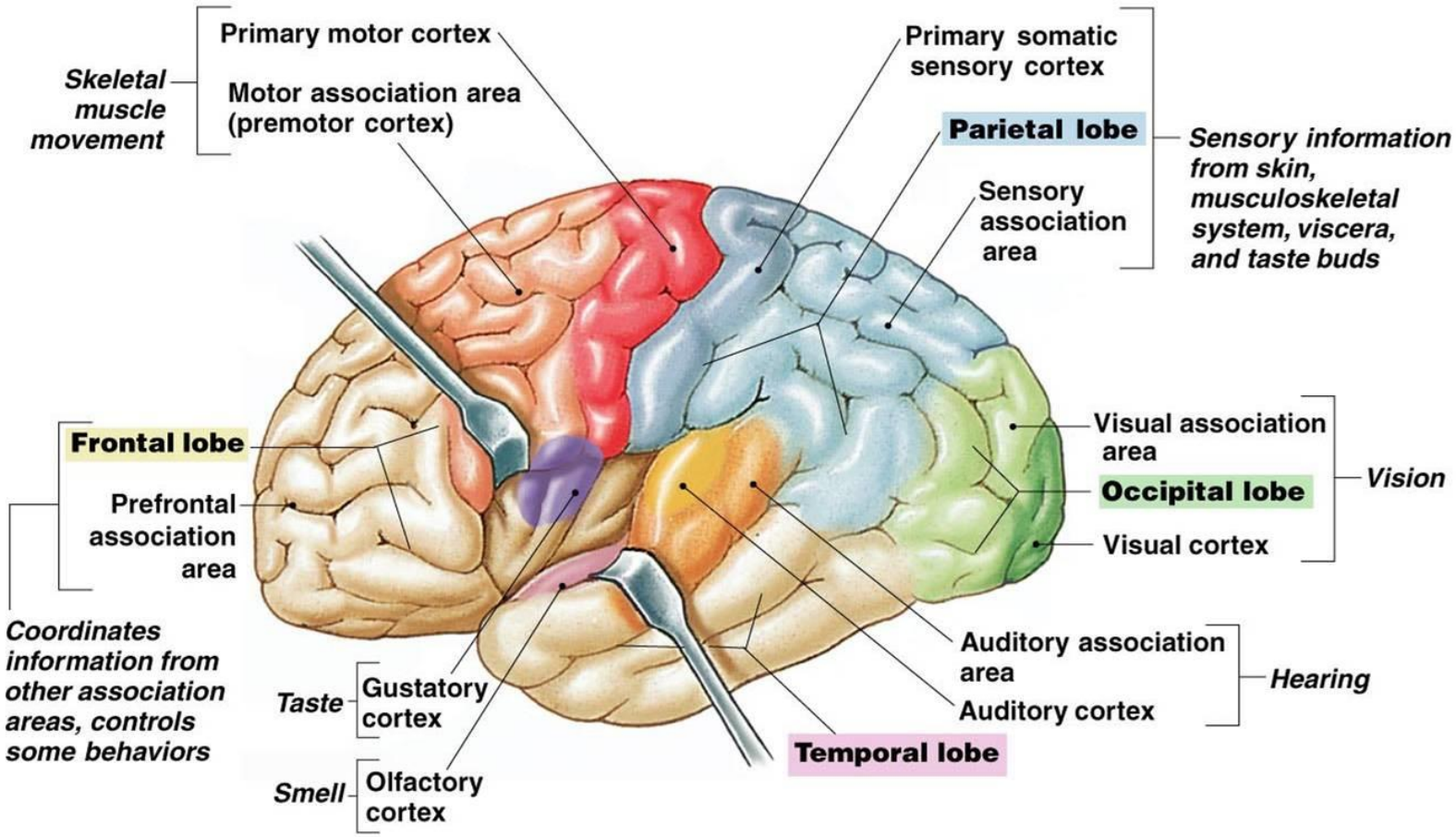


Sensation and Perception – Somatosensory, Audition, Gustation, Olfaction

10/3/2024

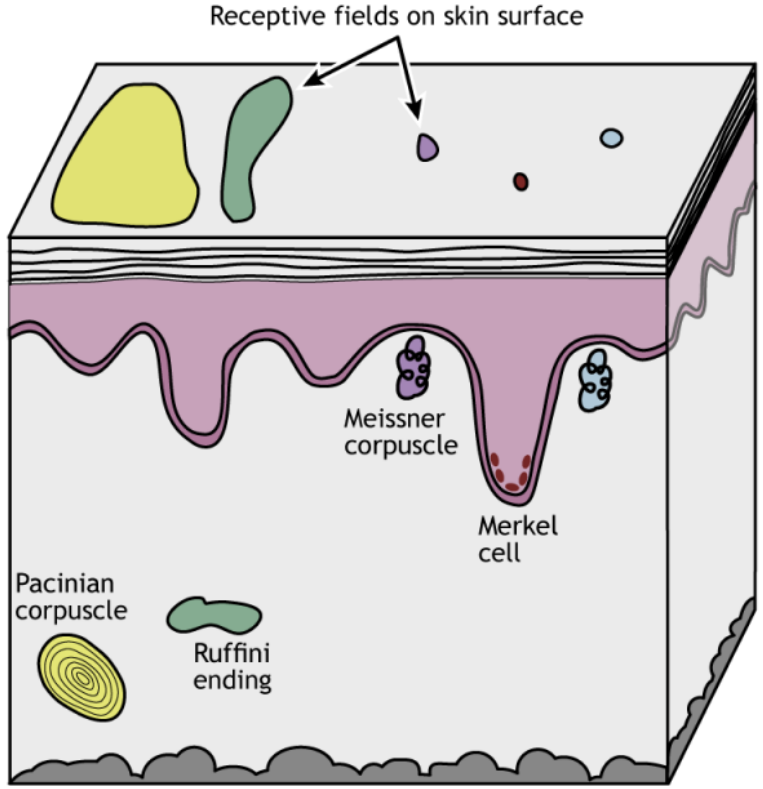

Primary motor cortex
Skeletal muscle movement
Motor association area (premotor cortex)
Primary somatic sensory cortex
Parietal lobe
Sensory association area
Sensory information from skin, musculoskeletal system, viscera, and taste buds
Frontal lobe
Prefrontal association area
Coordinates information from other association areas, controls some behaviors
Visual association area
Occipital lobe
Visual cortex
Vision
Auditory association area
Auditory cortex
Hearing
Taste
Gustatory cortex
Smell
Olfactory cortex
Temporal lobe

Somatosensory Systems

- **External stimuli**: information about interaction with external environment
  - Mechanoreceptors: touch and pressure
  - Thermoreceptors: temperature
  - Nociceptors: pain
- **Internal stimuli**: information about internal state of the body – hunger, thirst, breath, heart rate, gut motility
  - Visceral receptors: organ conditions (pressure, chemical)
  - Nociceptors: pain
- **Proprioception** – sense of body position and movement
  - Muscle spindles: changes in muscle length
  - Golgi tendon organs: tension in tendons
  - Joint receptors: joint position

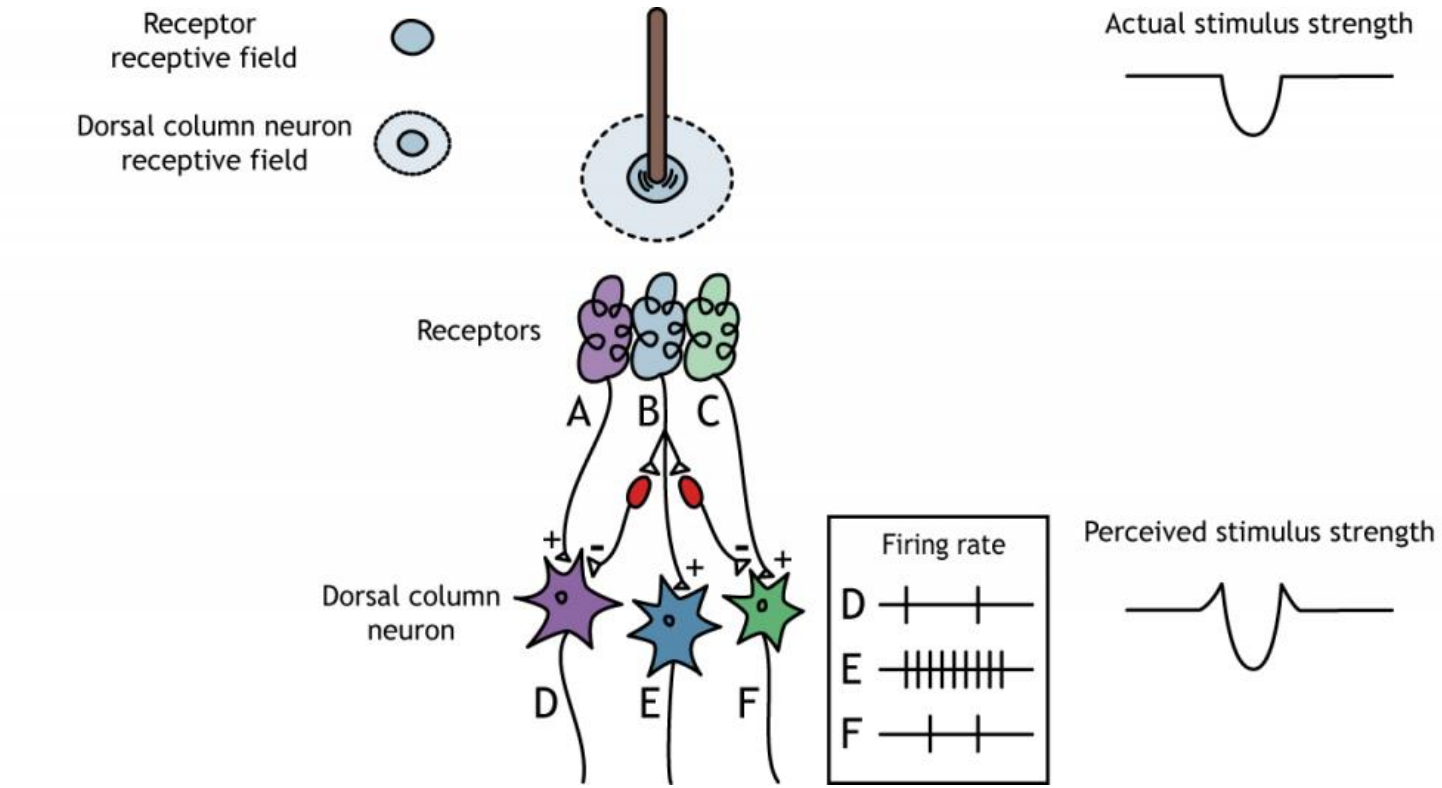
Touch pathway 1: Dorsal Column-Medial Lemniscus (DCML) pathway

- **Encapsulated receptors** – complex structures enclosed in the membrane for specialized stimulus detection
- **Pacinian corpuscles** – vibration, deep pressure
- **Meissner corpuscles** – fine touch
- Slow responding cells slowly adapt, firing action potentials across whole stimulus
- Help with pressure and shape
- **Ruffini endings** – stretch, sustained pressure
- **Merkel cells** – light pressure, texture
- Fast responding cells rapidly adapt, firing action potentials only when stimulus is changing
- Help with movement and vibration
- **Receptive field** dictates where on the skin the cell is sensitive to stimulus



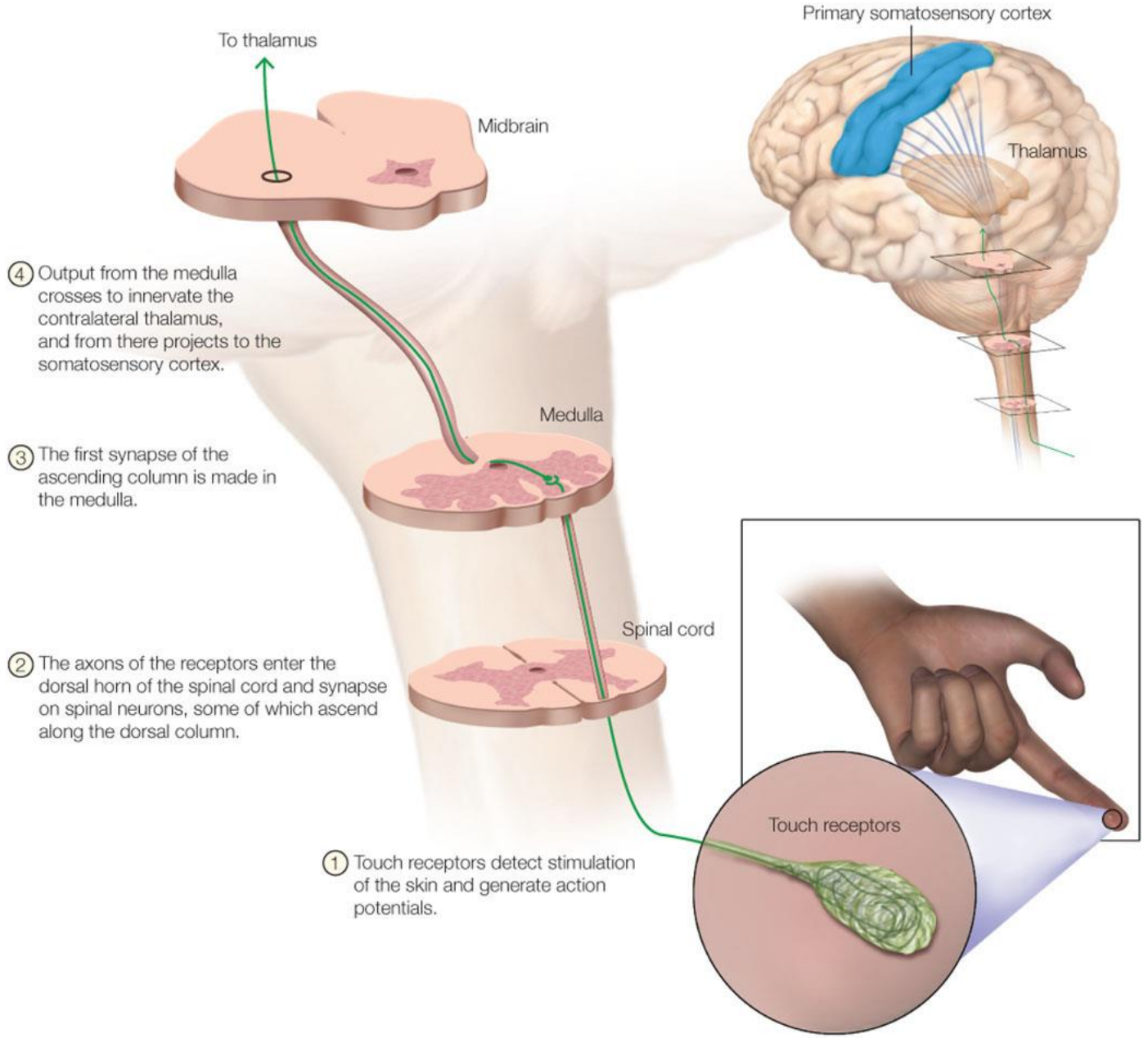
Lateral Inhibition

- Enhance perception of edges by inhibiting surrounding nerves



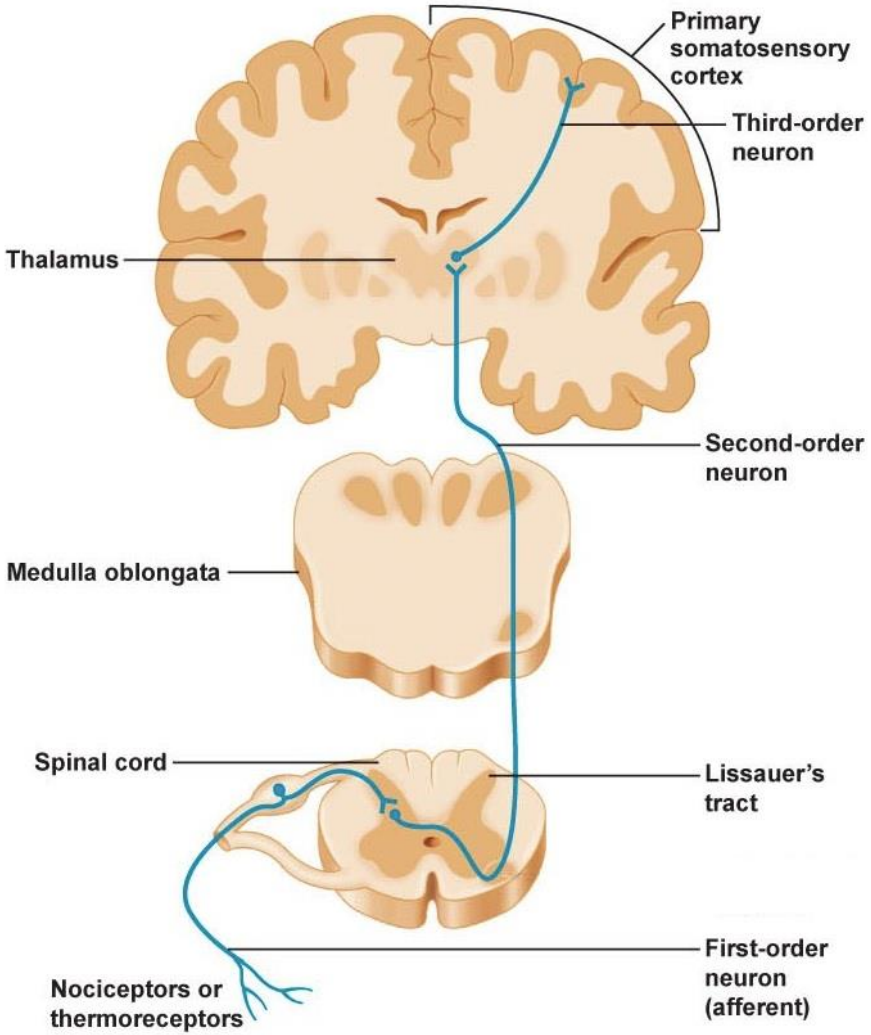
DCML pathway

- First-order neuron: Cell receptor on skin with cell body in **dorsal root ganglion** projects through dorsal horn of the spinal cord →
- Second-order neuron: **medulla (brainstem) decussates (crosses)** to the →
- Third-order neuron: **contralateral thalamus → somatosensory cortex**



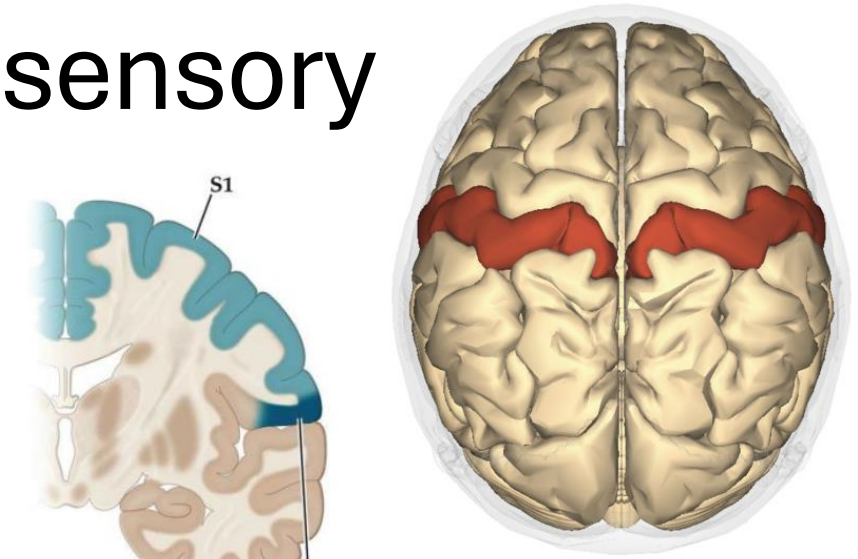
Touch pathway 2: Spinothalamic pathway

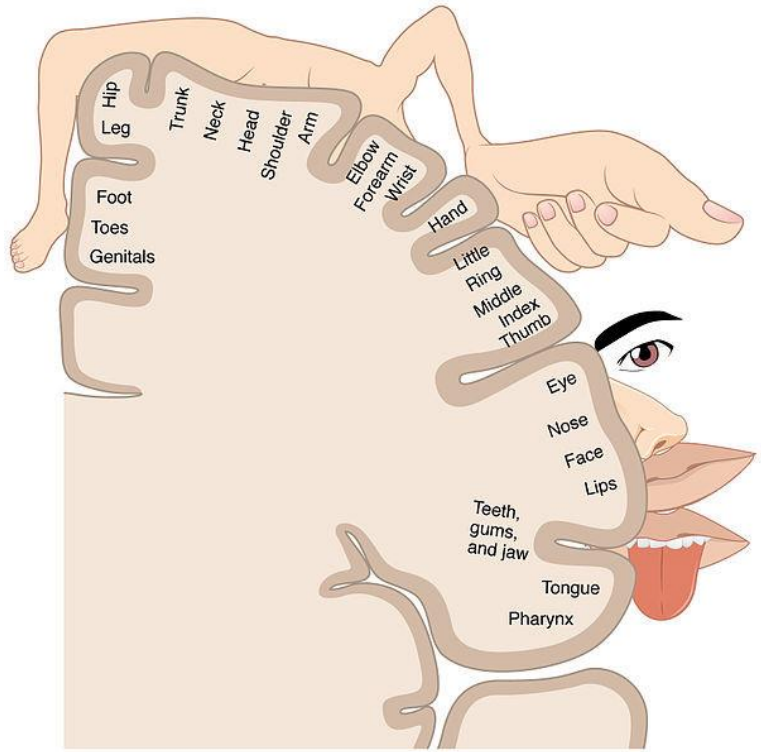
- **Free nerve endings** – no specialized encapsulation, allowing them to respond to a broader category of stimuli
- **Nociceptors** (pain) – respond to potentially harmful stimuli like extreme mechanical force, extreme temperature, or chemical irritants
- **Thermoreceptors** (temperature) – temperature-sensitive ion channels respond to temperature change
  - Hot channels like TRPV1 also respond to capsaicin
  - Cold channels like TRPM8 also respond to menthol
- **Mechanoreceptors** (crude touch, pressure) – mechanosensitive ion channels depolarize in response to deformation
- Many of these cells are **polymodal** – able to respond to multiple different stimuli
- Uses **unmyelinated fibers** that transmit slower signals



Primary and Secondary Somatosensory Cortex (S1 and S2)

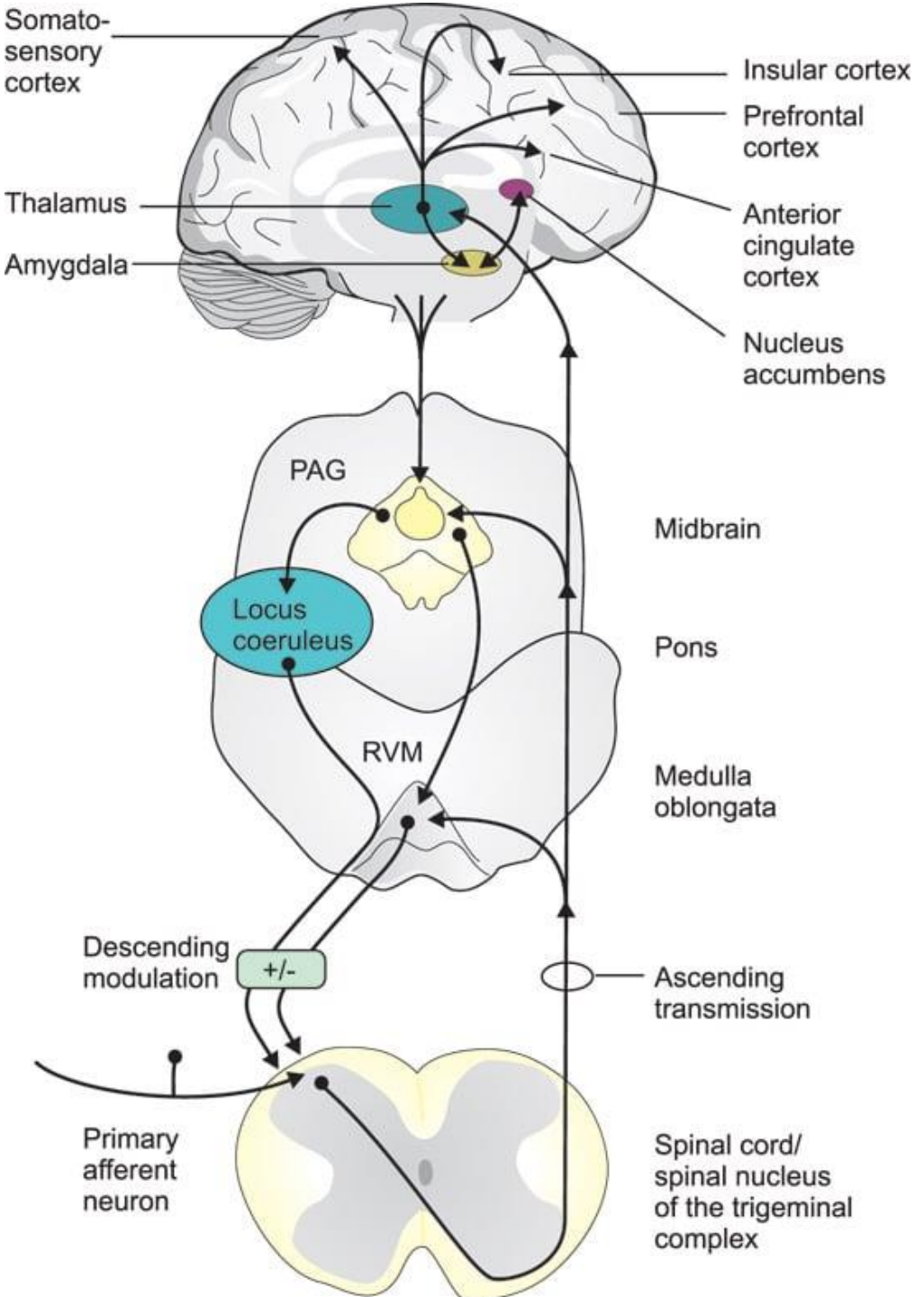
- **S1**: sensory homunculus – localization of stimulus on the body
  - Receives input from **thalamus**
  - Projects to **S2**, **motor cortex**, **posterior parietal cortex (PPC)**, **limbic system**
- **S2** – integrates complex touch information to identify textures and shapes, coordinates both sides of the body, integrates touch with emotion, memory and cognitive functions
  - Receives input from **S1** and **thalamus**
  - Projects to **motor cortex**, **PPC**, **insula**, **PFC**, and **limbic system**





Pain

- **Nociceptive pain –** activation of pain receptors due to injury, inflammation, physical damage
- **Neuropathic pain –** caused by nerve damage
- **Visceral pain –** pain from internal organs
- **Pain matrix –** integrates sensory information (**thalamus**, **S1**, **S2**), emotional processing (**insula** and **ACC**), cognitive evaluation (**PFC**), and memory and learning (**hippocampus** and **amygdala**) to create the overall pain experience
- **Descending pain modulatory system** can enhance or suppress pain
  - Stress can release opioids and cannabinoids to inhibit pain
  - Paying the right kind of attention to pain (mindfulness) can alter how it is experienced, even transforming it into pleasure
    - Project curiosity or interest at the pain and release the sense of aversion or judgment. Accept the raw sensation, inspect its tone and texture



Itch

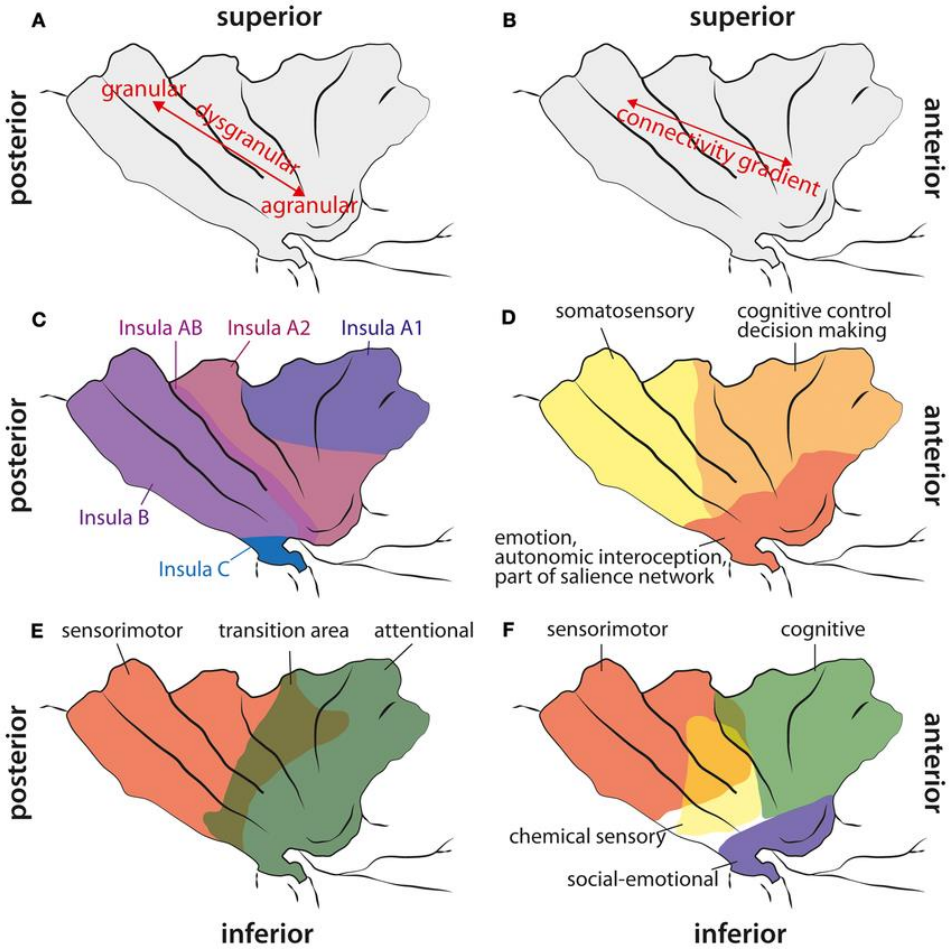
- **Pruriceptors** (itch receptors) – free nerve endings, distinct from pain
- Projects through **spinothalamic tract**, can be processed in **ACC** and **insula**, contributing to the compelling emotion and motivation underlying an itch
- Cross-talk between itch and pain pathways because they share overlapping circuits in the spinal cord
- **Counter-stimulation**: Scratching activates pain receptors which send competing signals that inhibit the itch signal
- **Histamine-mediated itch**: allergens, insect bites, skin irritation cause release of **histamine**, which binds to histamine receptors on free nerve endings
  - TRPV1 which also responds to *heat* can give *burning itch*
- **Non-histamine-mediated itch**: other chemicals can trigger itch response – seen in chronic kidney disease, liver disease, or other neuropathic conditions
  - TRPA1 can get activated by chemical irritants like mustard oil
- In cases of persistent itching, have to differentiate location of pathology and type of itch to be able to treat correctly – histamine? Nerve damage? Hypersensitization?

Tickle

- Combination of tactile inputs, emotional response, and anticipatory predictive processing
- **Knismesis** – light, gentle touch on the skin that triggers a reflexive withdrawal or an itch sensation
  - Low-threshold mechanoreceptors like Meissner's corpuscles and free nerve endings
  - Helps you detect small insects
- **Gargalesis** – stronger, laughter-inducing sensation from deep, more forceful pressure
  - Mechanoreceptors like Pacinian corpuscles and Meissner's
  - **ACC** is involved in emotional processing and conflict monitoring, to contribute to the laughter and/or discomfort of the inherent vulnerability
  - **PFC**'s involvement in self-monitoring and predictive processing prevents you from being able to tickle yourself
  - Unique to mammals, suggesting a social bonding role

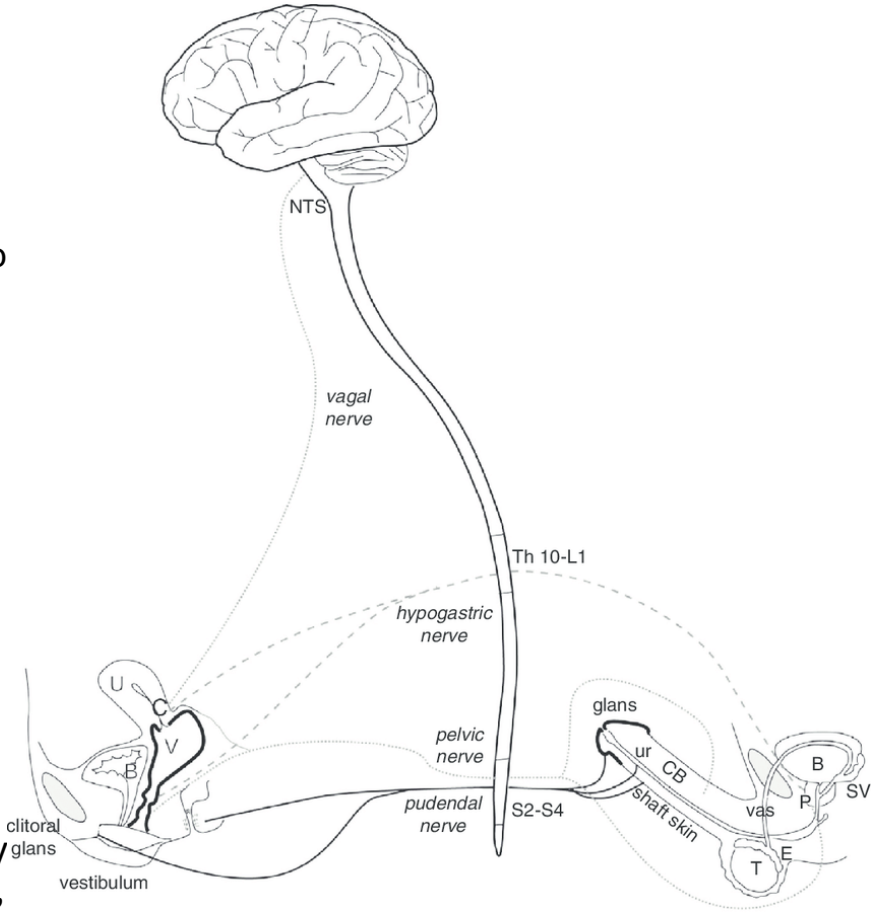
Interoception

- **Interoception**: perception of internal bodily states like heartbeat, breath, hunger, temperature
- Visceral sensations
  - Stretch and pressure – stomach fullness, bladder distension
  - Chemoreception – blood pH, CO2
  - Thermoreception – core body temperature
  - Pain and discomfort – cramping, nausea, heart discomfort, air hunger, etc
- **Vagus nerve** provides primary pathway to transmit non-painful signals, regulate autonomic functioning (**hypothalamus**), emotional processing (**insula** and **anterior cingulate cortex [ACC]**), and stress response (**amygdala**)
- **DCML** and **spinothalamic** pathways can send both pain and non-pain signals
- Some pathways (from gut and heart) bypass spinal cord and go straight to **brainstem** to regulate respiration, blood pressure, gastric motility
- **Insula** is the primary interoceptive integration hub with a **viscerotopic map** that organizes the signals

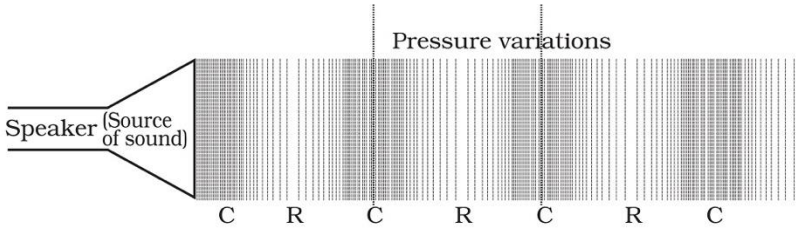


Erotic Sensation

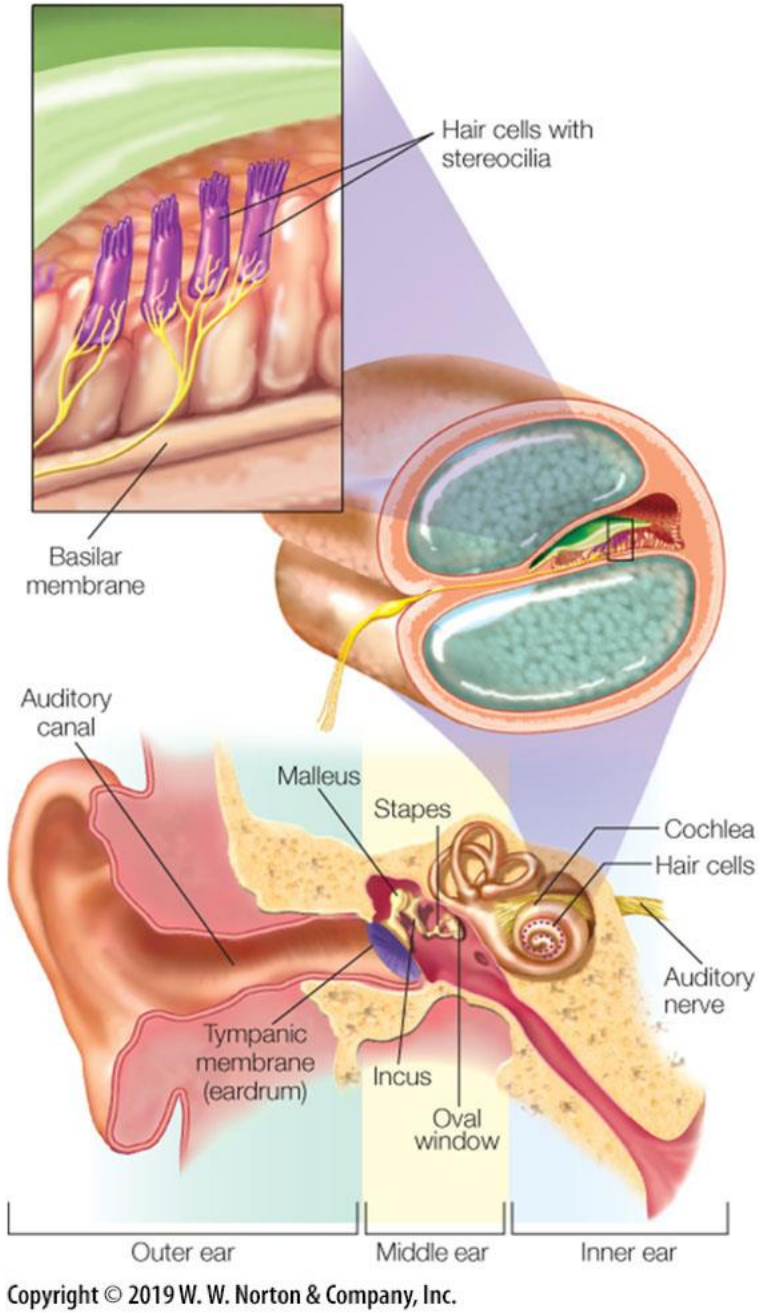
- Convergence of tactile, thermal, nociceptive, and proprioceptive inputs to create a unique experience of pleasure and arousal
- **Erogenous zones** – areas that are densely packed with specialized mechanoreceptors, making them highly sensitive to touch and pressure
  - **Genital Ruffini-like endings** – unique mechanoreceptors in genital skin sensitive to subtle pressure and stretch
  - **Genital Pacinian corpuscles** – unique corpuscles that respond to deep pressure and high-frequency vibration
- **Pudendal nerve** – carries both tactile and pain signals from genitals and surrounding areas
- **Pelvic and hypogastric nerves** – deep arousal signals from reproductive organs
- **Vagus nerve** – signals from cervix and uterus directly to brainstem, unique to women
- Stimulation and orgasm activates wide-spread activity across the whole brain: **S1** (tactile aspects), **S2** (pleasure), **insula** (interoception), **ACC** (emotional valuation and attention), **amygdala** (emotion and arousal), **thalamus** (sensory integration), **hypothalamus** (hormone release), **nucleus accumbens** (reward, motivation, pleasure), deactivation of **PFC** (loss of self-monitoring)
- High-frequency synchronization of gamma waves – intense, unified sensation of pleasure



Audition

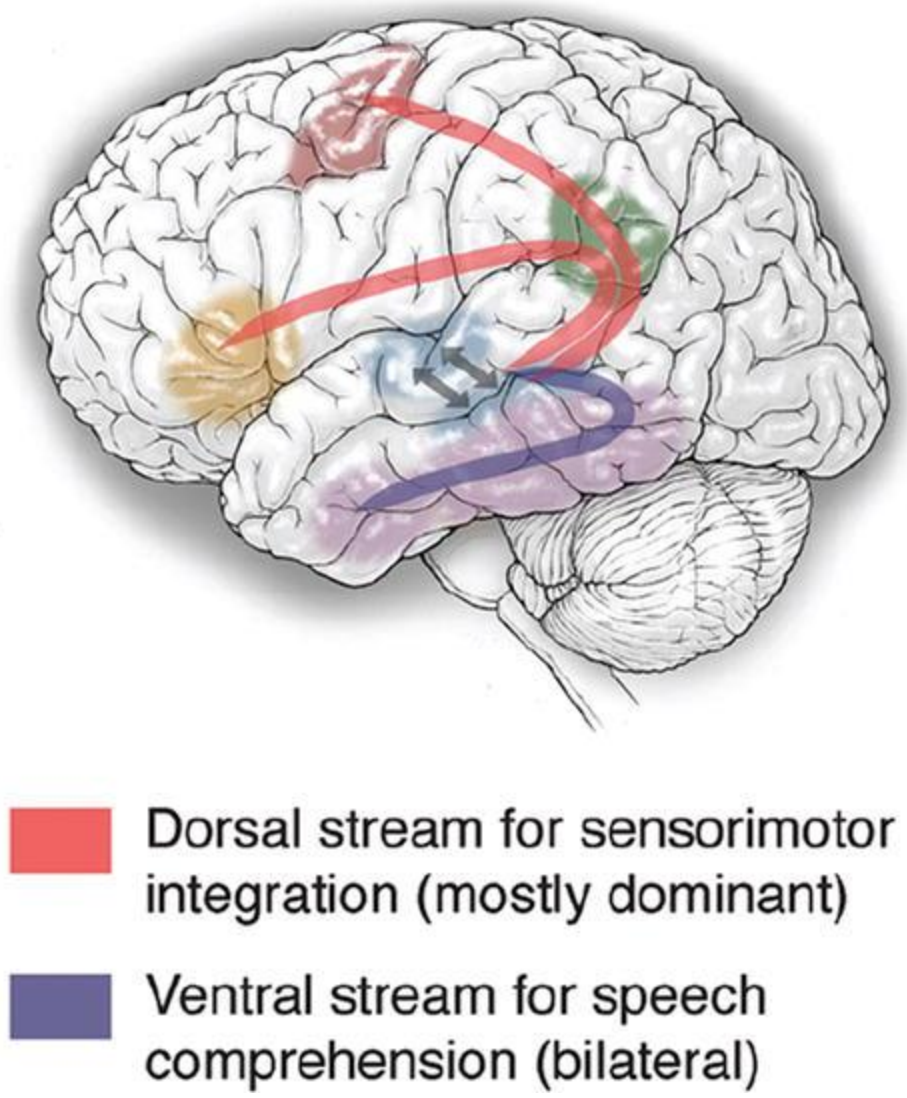


- Sensation and perception of sound
- **Outer ear** funnels sound waves to the **middle ear**, where they vibrate the eardrum, which vibrates the **ossicles** (malleus, incus, stapes) to amplify the sound
- Those vibrations transfer to the **cochlea** in the **inner ear**, where **hair cells** covert mechanical energy into electrical signals to be transmitted along the **cochlear (auditory) nerve** to the **brainstem**



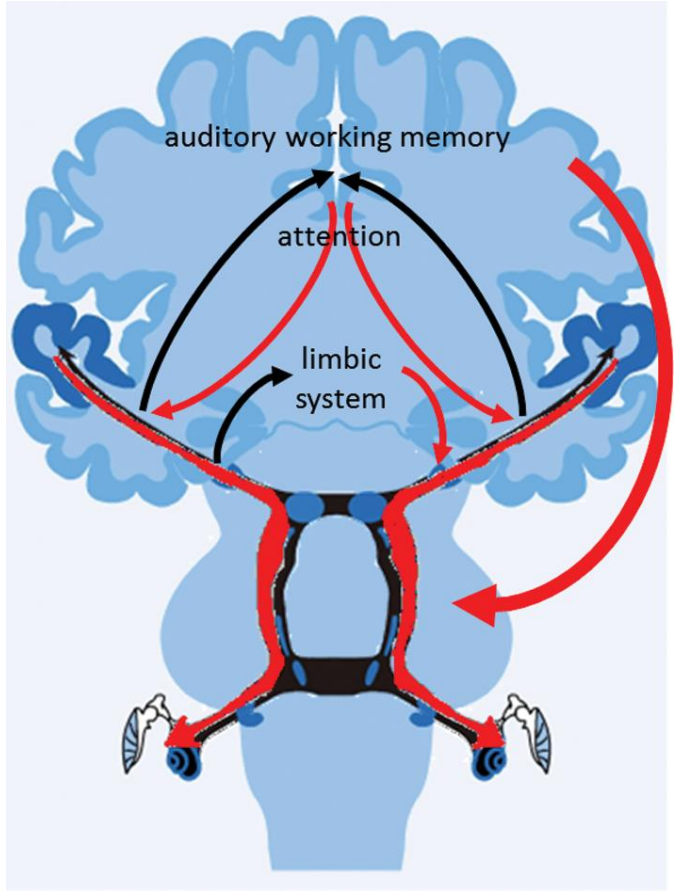
Auditory Pathway

- Primary auditory cortex (**A1**) processes basic sound features like frequency and amplitude
- Secondary auditory cortex (**A2**) involved in more complex sound processing like identifying distinctive sounds, localization, music, speech
- Dual-stream model:
  - **Dorsal (where/how)** – projections to **parietal lobe** and **premotor cortex** for spatial localization and sensorimotor integration
  - **Ventral (what)** – projections to **inferior frontal cortex (VAN)** for speech comprehension, semantic processing, sound identification



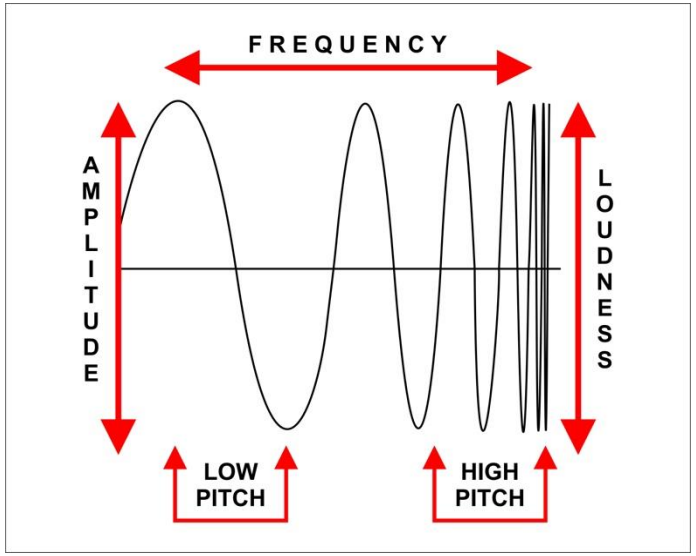
Auditory Cognition

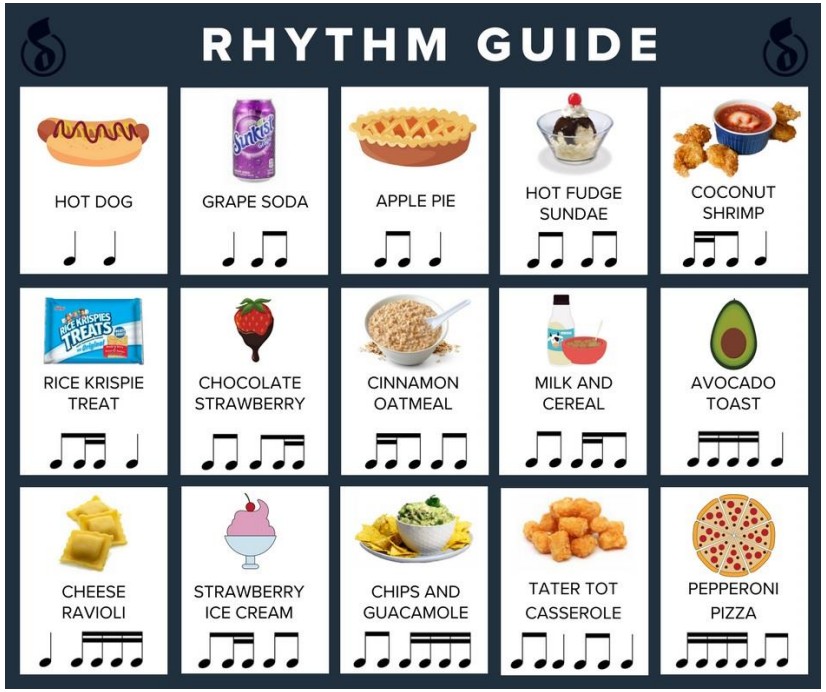
- Attention networks and **ACC** work together to filter out competing sounds to give you **selective attention** on one **auditory stream**
- **PFC** is engaged when you are rapidly switching between multiple auditory streams to maintain **divided attention**
- Attention networks engaged to maintain working memory of an auditory sequence – melodies, sentences
- **Source separation**: auditory cortex and attention networks can separate overlapping sounds into distinct sources
- **Predictive processing**: brain continuously generates and updates predictions about incoming sounds, anticipating speech, music, and environmental sounds
  - Deviations in expectation influence surprise, novelty detection, attention reallocation
- **Auditory imagery**: ability to internally "hear" sounds or music in absence of external stimuli
  - **A1/A2**, **PFC**, **parietal regions**
- **Inner voice** or monologue engages **premotor areas** to plan and simulate the motor actions necessary to speak, but the motor execution pathways are inhibited



Music and Rhythm

- **Music**: organized combination of sounds that convey meaning, emotions, and aesthetic experience
  - **Pitch**: note's frequency
  - **Harmony**: combination of notes to create complex interaction
  - **Melody**: sequence of notes perceived as a coherent whole
  - **Timbre**: higher order qualities (harmonics) on a sound that make it distinctive
- **Rhythm**: temporal pattern of sounds
  - **Beat**: regular pulse of the rhythm
  - **Tempo**: speed of the rhythm
  - **Meter**: structure of the rhythm (how many beats in a cycle?)
  - **Syncopation**: shifting rhythmic accents to weak or off-beats to make a rhythm more complex, distinctive, and evocative





Music and Rhythm Perception

- **Multimodal integration** allows for perception of music to be rich and rewarding
- **Audiomotor coupling** – **cerebellum** (fine tuning), **basal ganglia** (timing regulation), **premotor cortex** (motor planning), and **PPC** (body integration) are engaged to entrain and predict the rhythm so that you feel the beat
- Musical syntax – processed similar to language in **Broca's area (left inferior frontal gyrus)** to detect the "grammar" of music
- Attention and memory systems (working and long-term) engage to regulate expectation, prediction of notes and beats
- **Nucleus accumbens (dopaminergic reward)** activated to motivate and reinforce musical expectations, tension/release resolution
- **Ventral striatum** and **amygdala** contribute to affective response
- Largely lateralized to right-hemisphere
- It seems to be biologically innate – infants respond to rhythm, all cultures enjoy consonant harmonies

HOW MUSICAL TRAINING SHAPES THE BRAIN

INCREMENTS IN STRUCTURE AND FUNCTION
MUSICIANS COMPARED TO NON-MUSICIANS

Frontal Lobe

Increased grey matter volume
superior, medial, inferior frontal gyrus – executive functions

Increased fMRI activation
primary & supplementary motor areas – motor preparation and execution
Broca's area – speech production

Temporal Lobe

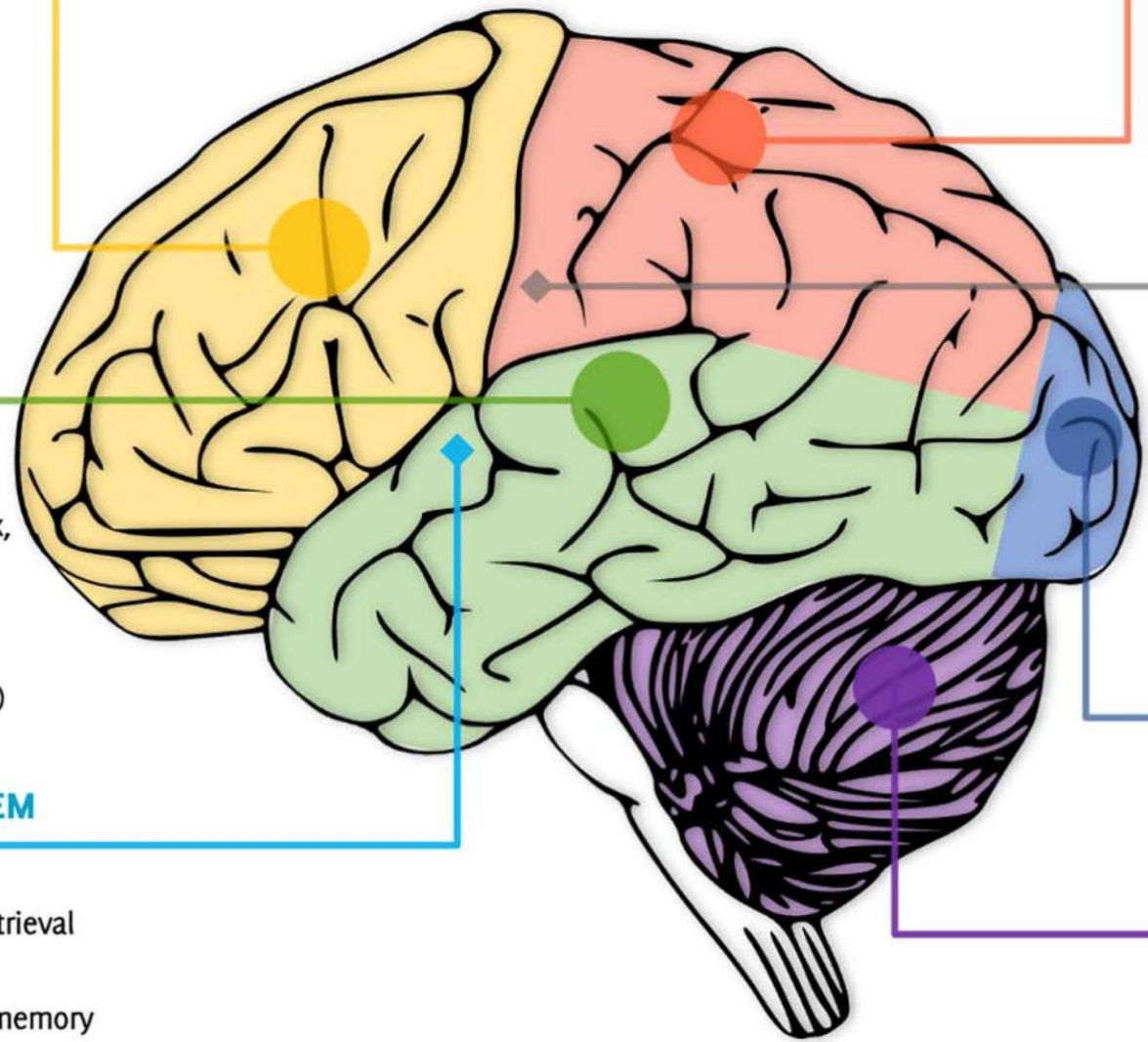
Increased grey matter volume &
Increased fMRI activation
Heschl's gyrus – primary auditory cortex, pitch perception
superior temporal gyrus – auditory processing

Increased mismatch negativity (EEG)

Basal Ganglia & Limbic system

Increased grey matter volume
hippocampus – memory formation & retrieval

Increased EEG response
temporal-limbic areas – emotions and memory



Parietal Lobe

Increased grey matter volume
primary somatosensory cortex – touch perception

Increased fMRI activation
supramarginal gyrus – syntax processing and attention

White Matter Tracts

Increased white-matter integrity
corpus callosum – connects brain hemispheres
corticospinal tracts – connect motor areas with spinal cord
short fibres – connect sensory and motor areas
striatum – motor planning and reward perception

Occipital Lobe

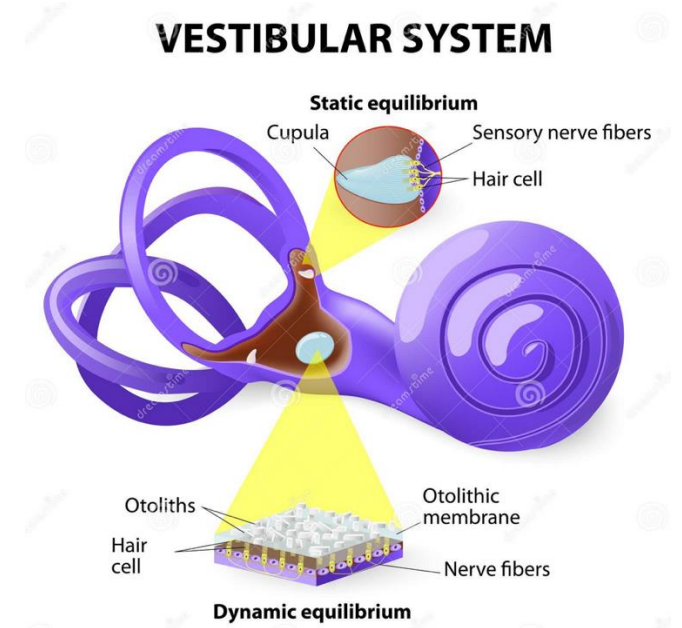
Increased grey matter volume
lingual gyrus - score reading

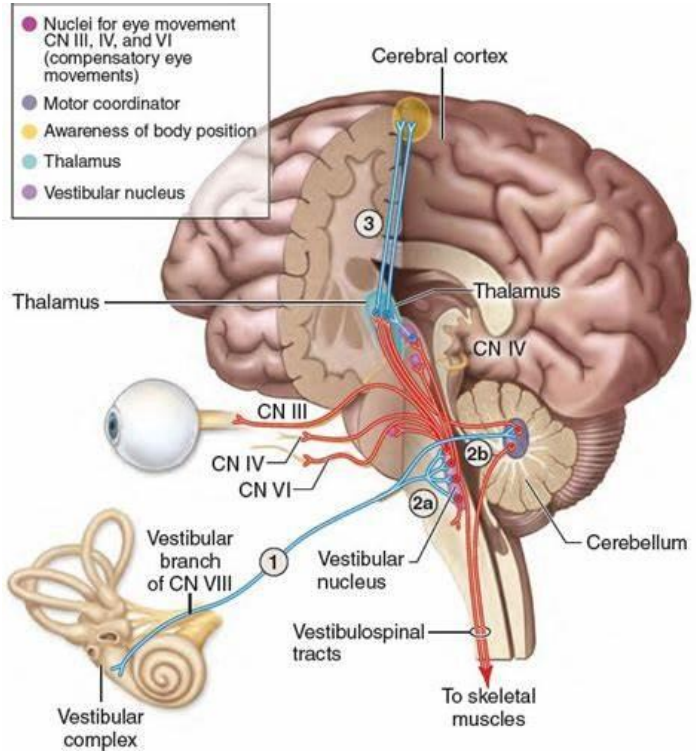
Cerebellum

Increased grey & White matter volume
movement coordination and motor learning

Vestibular System

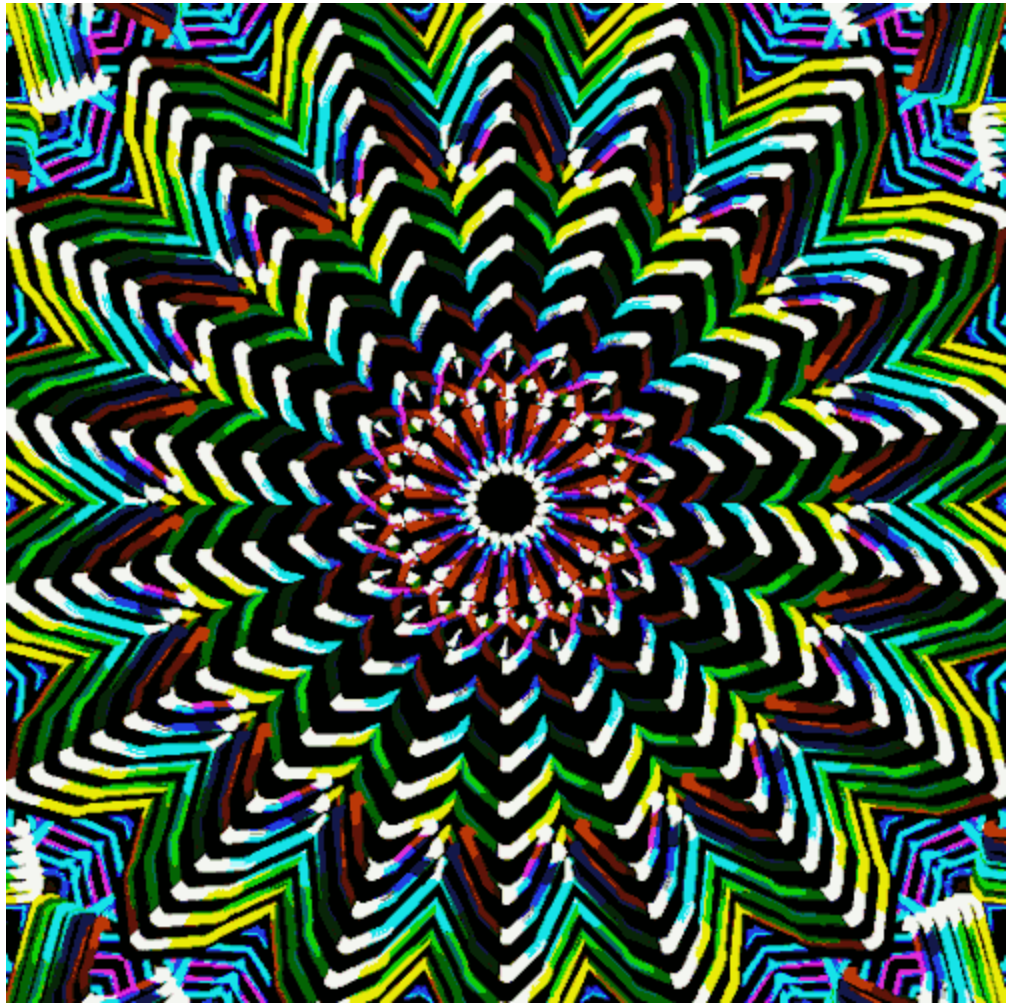
- Responsible for maintaining balance, coordinating head and eye movements, detecting linear and rotational movements, allowing for postural control and sense of felt spatial orientation
- **Semicircular canals** – detect rotational movements along three axes of rotation in each of the three canals
  - Regulate static equilibrium (unchanging)
- **Otolith organs** – detect linear acceleration (change in velocity) and head tilt
  - Regulate dynamic equilibrium (changing)
- **Endolymph fluid** moves within the canals to bend the **hair cells** which trigger nerve impulses in the **vestibular nerve** that transmit to the **vestibular nuclei** in the **brainstem** to be integrated
  - Projections to **cerebellum** (motor coordination), **oculomotor nuclei** (eye movement, gaze stability), **thalamus** (sensory relay), **insula** and **parietal cortex** (multisensory integration of sense of body), **spinal motor neurons** (postural control), **hippocampus** (spatial memory and navigation)
- **Vertigo** – sensation of spinning or dizziness due to mismatch of vestibular input with other sensory input





How Psychedelics Alter Perception

- Activation of **5-HT2A serotonin receptors** enhances sensory processing and neural excitability
- **Thalamic filtering** is reduced, allowing more information to reach the cortex
- More excitability and information in the cortex leads to more intense sensory experiences, increased connectivity between sensory domains (**synesthesia**), and amplified emotions
- The geometric patterns seen in psychedelic hallucinations may be the manifestation of self-organizing activity in the neural networks – may represent the shape of the neural circuits themselves

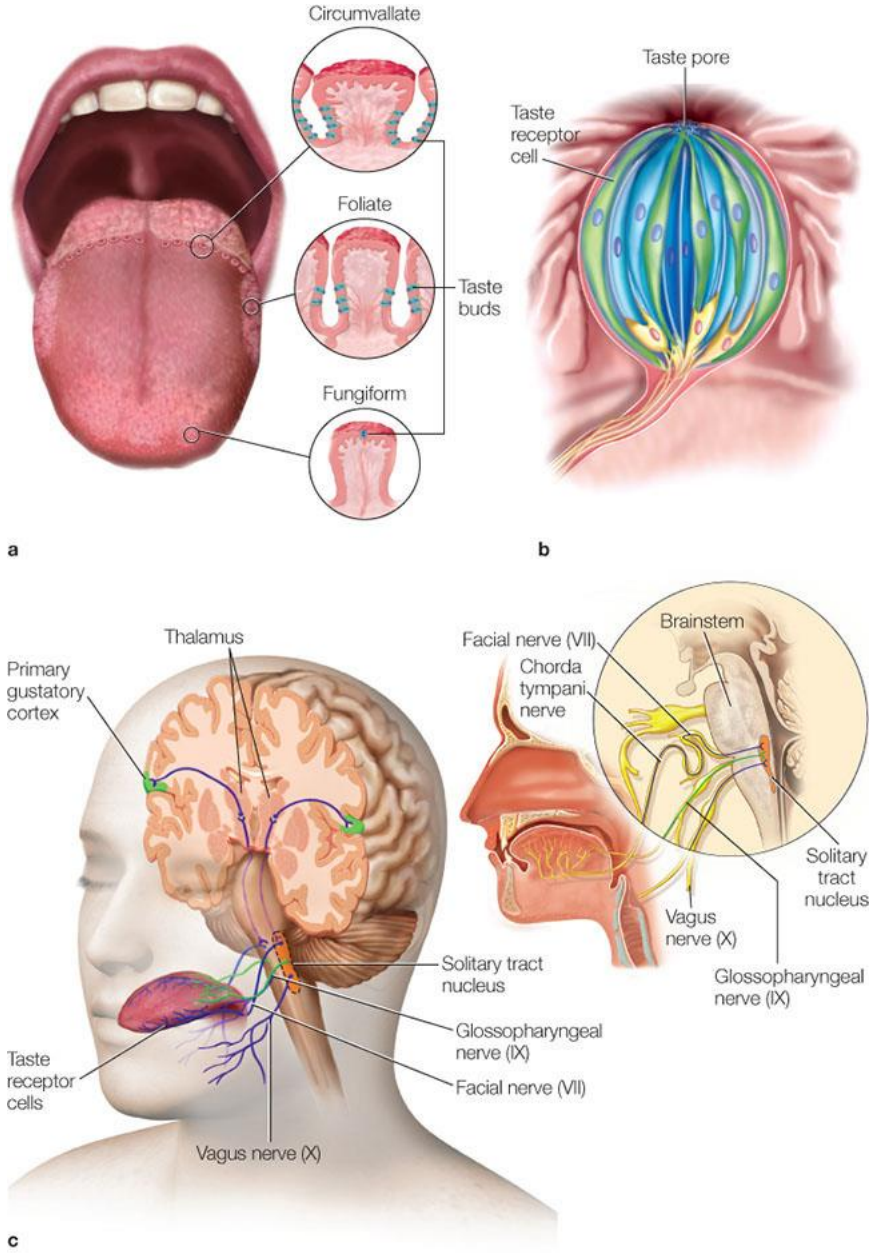


Autonomous Sensory Meridian Response (ASMR) and Frisson

- **ASMR**: A prolonged gentle tingling sensation that typically starts at the scalp and moves down the back of the neck and spine, often felt as pleasurable and relaxing
  - Can be triggered by delicate sounds and sensations like whispering, tapping, crispness of texture, detailed tasks, and/or close personal attention
  - Engages **S1**/**S2**, **insula**, **PFC**, seems to overlap with social bonding and affective touch
- **Frisson**: a sudden, wave-like shiver or tingle that spreads quickly across the skin – the "chills" or "goosebumps" – often felt with intensity, can be across the whole body or localized to neck, arms
  - Can be triggered by powerful, exhilarating stimuli like a crescendo in music, inspiring movie scene, awe-inspiring performance, unexpected beauty
  - Engages **amygdala** (emotion) and **ventral striatum** (reward and dopamine), seems to work with emotional engagement

Gustation

- Taste receptor cells on the tongue respond to different chemical compounds – sweet (sugar), sour (acidity), salty (electrolytes), bitter (toxic), savory (fat and protein)
- Transmitted through **brainstem** and **thalamus** to **gustatory cortex** in the **insula**, and further integration in **orbitofrontal cortex (OFC)**, **ACC** for memory, emotion, reward processing
  - Integration with olfactory inputs, texture, and temperature creates complex flavor experience



Olfaction

- **Olfactory receptors** in nasal cavity detect airborne chemicals
- Receptors transmit to olfactory bulb (mapping) to **olfactory cortex** (processing, identification) to higher-order projections:
  - **Orbitofrontal cortex (OFC)** for integration with gustation for flavor perception
  - **Amygdala** for emotion, memory
  - **Hippocampus** for memory
  - **ACC** for attention, emotional evaluation
- Direct connection to **limbic system**, no thalamic relay, allows smell to be a deeply direct and emotional experience
- **Vibrational frequency** of odorants allows for highly sensitive response through **quantum tunneling**