

PL3232 Biological Psychology

Spring 2021

Section 2

Lecturer: Prof. Lim Ziqiang Julian

2.1. Neuroimaging.

2.1.1. Introduction.

- (1) Neuroimaging allows us to study the brain *in vivo* (i.e. in a living organism), and that has led to deep insights in how the human brain functions.
- (2) All scientific methods have advantages and disadvantages.
 - The research question should drive what method you use, and not the other way round.
- (3) All behaviour originate in the brain.
- (4) Although the brain has specialized areas, it also operates in parallel and as a series of networks.

2.1.2. Electroencephalography (EEG).

- (1) We are measuring the manifestation of electrical activity in populations of neurons in the brain.
 - For a signal to be detected, neurons must be **active in synchrony**, and they must also be oriented in a direction such that **their activity does not cancel out**.
 - Hence, only a subset of brain activity can be recorded.
 - Dendrites that are oriented in parallel along the cortical sheet are thought to contribute the strongest signals measurable with EEG/MEG.
 - Axons are more randomly located, resulting in currents from presynaptic APs cancelling each other out.
 - However, their postsynaptic electrical activity (EPSP) sums, creating a **dipole**.
 - Once transformed, the EEG power spectrum is then subdivided into power bands, either by fixed intervals or based on the individual alpha frequency.
 - **Event-related potentials (ERP)** are another major source of information that can be extracted from an EEG dataset.
 - They are **averaged segments of EEG data** that are **time-locked to the onset of a particular event of interest**.
 - ERPs are regarded as **manifestations of specific psychological processes**, and differences in ERP components are interpreted as **differences in underlying cognitive activity**.
- (2) Advantages:
 - High temporal resolution (milliseconds)
 - Gold standard of measuring certain brain states

- Relatively cheap and portable
- Repeatable
- Non-invasive
- Easy to use

(3) Disadvantages:

- Poor spatial resolution
- Signal bias (activity in certain brain regions cannot be recorded)
- Susceptibility to artifacts:
 - Eye blinks and movements
 - Muscle artifacts
 - Movement artifacts
 - Changes in skin potential
 - Interference
 - Faulty electrodes and instrumentation

2.1.3. Magnetic resonance imaging (MRI).

(1) What are we measuring?

- Brain structure
 - Certain atomic nuclei absorb and subsequently re-emit radio frequency (RF) energy when placed in a strong magnetic field.
 - The amount of RF detected from each point in space can tell us something about the composition of tissue in that part of the brain (e.g. white matter vs gray matter).
 - This gives us pictures of **brain structure**.
- Brain function
 - Brain areas that are active are sent an excess of oxygenated blood, increasing the ratio of oxyhaemoglobin to deoxyhaemoglobin.
 - As these two molecules have different magnetic properties, we can detect this change using functional MRI scans that use **blood-oxygenation level dependent (BOLD)** contrast.
 - This can give us pictures of **brain function** while doing a cognitive task.

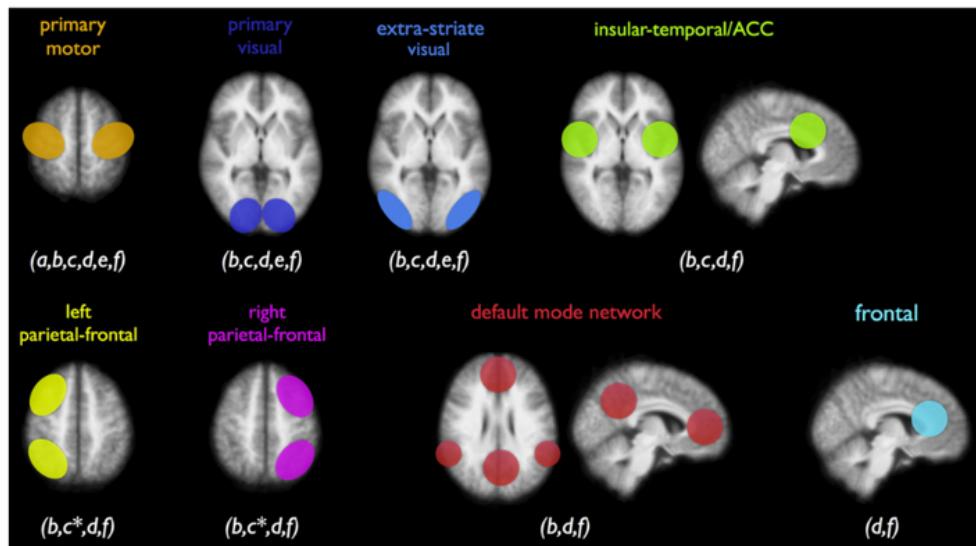
(2) Advantages of fMRI:

- Good spatial resolution
- Information can be displayed in 3D
- Non-invasive
- Repeatable
- Structure and function are concurrently visible
- Range of task designs allow us to ask a variety of research questions

(3) Disadvantages of fMRI:

- Poor temporal resolution
- Susceptibility of images to various artifacts:

- Subject-related artifacts (e.g. head motion, uncomfortable participants)
 - Equipment-related artifacts
 - Exclusion criteria (not all individuals are suitable for using it)
 - Expense
- (4) Among the most important findings of fMRI analysis is that the brain consists of a small number of robustly reproducible networks.



2.2. Vision I.

2.2.1. Anatomy of the eye.

- (1) The **eye** is composed of neural (retina) and non-neural tissue (the rest of the eye).

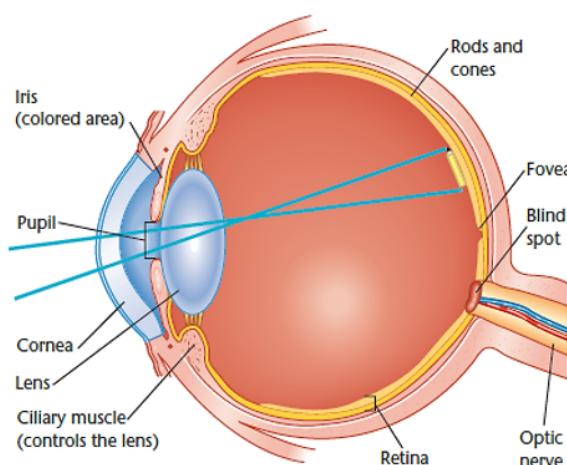


FIGURE 2.1. Cross section of the eye.

The **retina** is a thin neuronal layer in the back of the eye. The optic nerve (composed of axons from *ganglion cells*) exits the retina through the optic disc, which lacks retinal tissue, thus creating a **blind spot**.

- (2) The retina is organized in 3 layers of cells:
- photoreceptor layer,
 - horizontal + bipolar + amacrine layer, and
 - ganglion cell layer.

There are 5 types of cells:

- photoreceptors**,
- horizontal cells**,
- bipolar cells**,
- amacrine cells**, and
- ganglion cells**.

Each cell type consists of a variety of morphologically different cells, e.g. photoreceptors can be subdivided into 3 kinds of cones and 1 type of rod cells.

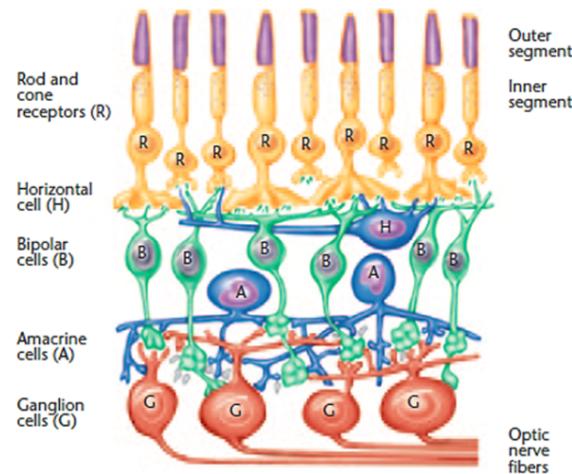


FIGURE 2.2. Structure of the retina.

- Photons are absorbed by photoreceptors, which synapse onto bipolar cells.
 - Bipolar cells themselves synapse onto ganglion cells.
 - Horizontal and amacrine cells modulate photoreceptors, bipolar, and ganglion cells.
- (3) **Cones** are denser in the fovea (\therefore has greatest perception of detail), and almost absent in the periphery. **Rods** are denser in the parafoveal region (adjacent to the fovea), and absent in the fovea itself.

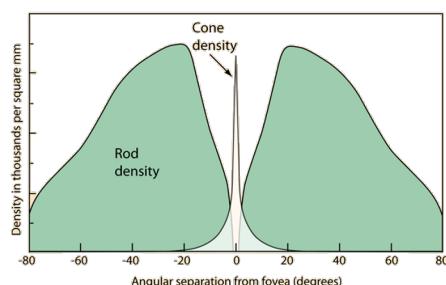


FIGURE 2.3. Density of photoreceptors across the retina.

Characteristic	Foveal vision	Peripheral vision
Receptors	Cones only	Proportion of rods increases toward periphery
Convergence of input	Each ganglion cell is excited by a single cone	Each ganglion cell is excited by many receptors
Brightness sensitivity	Distinguishes among bright lights, but responds poorly to dim light	Responses well to dim light but not bright light
Sensitivity to detail	High detail; each cone's own ganglion cell sends a message to the brain	Poor detail; many receptors converge their input onto a single ganglion cell
Color vision	Good	Poor

2.2.2. Phototransduction.

- (1) **Phototransduction** is the conversion of electromagnetic/light energy into electrochemical energy (cell polarization) in neurons.
- (2) Rods contain **rhodopsin**, whereas cones contain **iodopsin**.
- (3) Light **inhibits** photoreceptor activity.

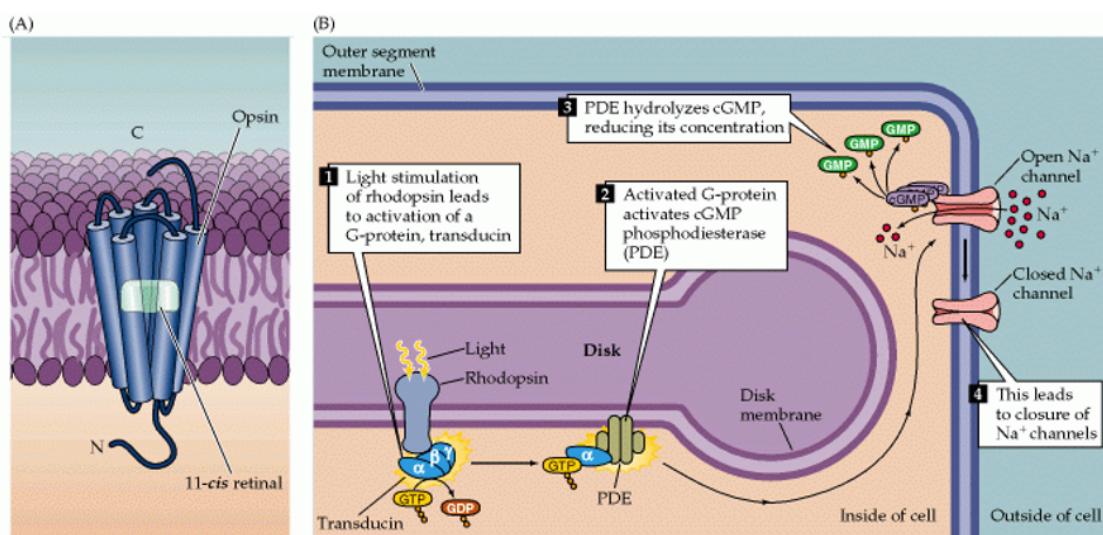


FIGURE 2.4. Phototransduction.

- (a) In the dark, Na⁺ channels are kept open by circulating cGMP, so the cell is *depolarized by default*.
- (b) When photons strike the retina, rhodopsin/iodopsin absorbs the photons, leading to a change in its configuration (bleaching).
- (c) The release of the G-protein activates cGMP phosphodiesterase (PDE), which hydrolyzes cGMP, thus reducing its concentration.
- (d) This leads to the closure of membrane Na⁺ channels, leading to the hyperpolarization of the cell (and less release of neurotransmitters).
- (e) The regeneration of rhodopsin occurs primarily in darkness.

2.2.3. Color vision.

- (1) The **Trichromatic/Young-Helmholtz Theory of Color Vision** proposes that colors of light are determined by the relative rates of response of the 3 photoreceptor types.

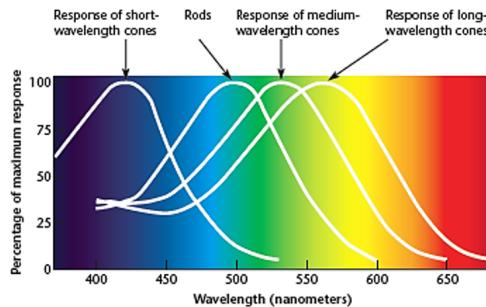


FIGURE 2.5. Sensitivity range of different receptors.

- Long and medium wavelength cones are far more abundant than short wavelength cones, thus it is often easier for us to see red/yellow/green dots than blue dots (which may appear black from a greater distance).
 - The short wavelength cones are approximately evenly distributed across the retina, but the other kinds of cones are distributed haphazardly (and their density differs greatly between individuals).
- (2) The **Opponent Process Theory** proposes that we perceive color in terms of opposites. There are continuums from:

- red to green,
- blue to yellow, and
- bright to dark.

After staring at one color in one location long enough, we fatigue that response and it swings to the opposite end.

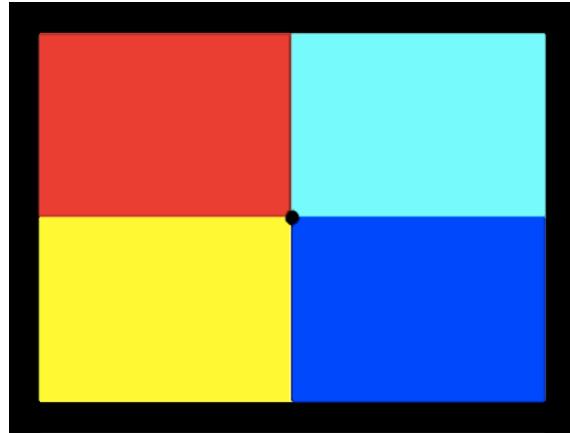


FIGURE 2.6. Stare at this image for a minute, then look at a white wall.

This theory helps to explain the complementary color afterimage – which cannot be explained by the trichromatic theory.

- (3) The **Retinex Theory** proposes that color identity is defined in the cortex by the interaction between the wavelength (brightness and color) of an object, and the wavelengths of its surround.

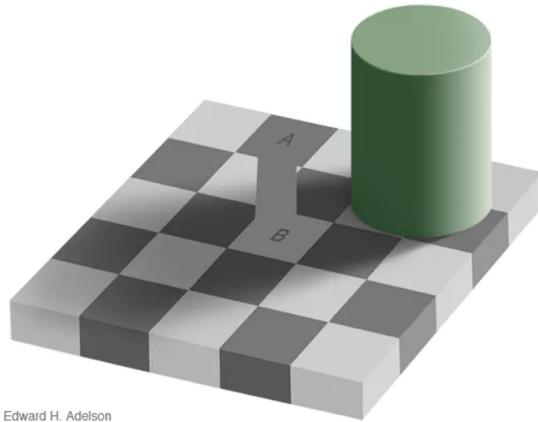


FIGURE 2.7. Adelson's famous checker shadow illusion.

2.3. Vision II.

2.3.1. On and off responses in the retina.

- (1) **ON** responses refer to increases in response to increases in light. For example, bipolar and ganglion cells may increase (may also decrease) their activity when light turns on.

Conversely, **OFF** responses refer to increases in response to decreases in light. For example, cones and rods decrease their activity when light hits them, and increase their activity when light is turned off.

- (2) ON responses occur in bipolar cells with **metabotropic glutamate receptors** (sign-reversing synapses).

- (a) When light is turned off, the photoreceptor linked to the bipolar cell is depolarized and releases glutamate.
- (b) When glutamate binds to the receptor on the bipolar cell, the neuron hyperpolarizes.
- (c) Thus, these bipolar cells decrease their activity in response to decreased light.

OFF responses occur in bipolar cells with **ionotropic glutamate receptors** (sign-preserving synapses).

- (a) When glutamate binds to the receptor on the bipolar cell, the neuron depolarizes.
- (b) Thus, these bipolar cells increase their activity in response to decreased light.

2.3.2. Center-surround organization.

- (1) The **receptive field** of an *individual sensory neuron* is the region of space where stimulation can trigger a response in the neuron.

- (2) **Center-surround** receptive field structure can be either:

- (a) **center-ON surround-OFF**: light excites the center and inhibits the surround.
- (b) **center-OFF surround-ON**: light inhibits the center and excites the surround.

The receptive field of a neuron *may* have a center-surround organization.

- (3) The center-surround is organized by inhibiting the center photoreceptor via horizontal cell activity (i.e. surrounding photoreceptors excite a horizontal cell, which inhibits the center cone).

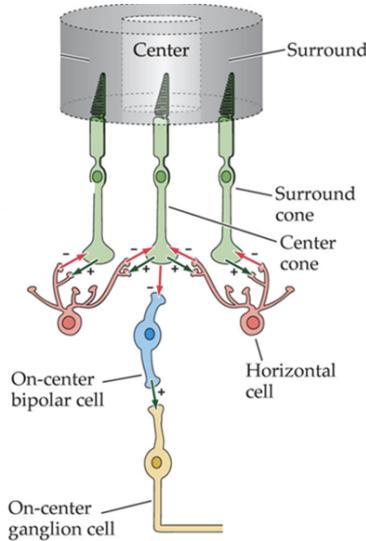


FIGURE 2.8. Center-surround receptive field.

- (4) There are three types of ganglion cells, each with different properties.

Parvocellular	Magnocellular	Koniocellular
Located in or near the fovea	Distributed evenly throughout the retina	Found throughout the retina
Smaller cell bodies and receptive fields	Larger cell bodies and visual fields	Small cell bodies
Sensitive to color and visual detail	Sensitive to large overall patterns and movement	Several functions; axons terminate in different places

2.3.3. Targets of the optic nerve.

- (1) The retina projects to multiple structures, including:

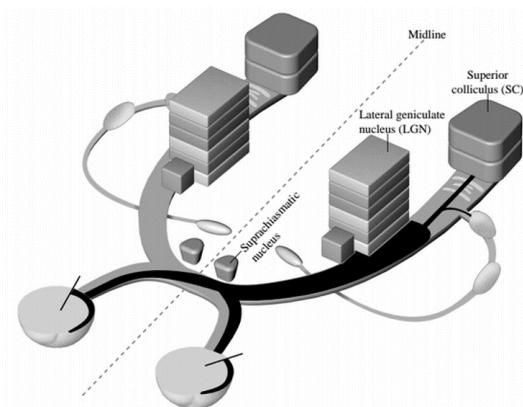


FIGURE 2.9. Targets of the optic nerve.

- (a) **Suprachiasmatic nucleus:** part of the hypothalamus involved in controlling circadian rhythms.
- (b) **Pretectal nuclei:** part of the midbrain involved in visual reflexes (i.e. optokinetic nystagmus, pupillary light reflex, vestibulo-ocular reflex).
- (c) **Superior colliculus:**
- Located in the midbrain.
 - Essential for visuomotor transformation.
 - Orient the animal to objects of interest using eye movements (saccades).
 - May have a role in visual processing.
- (d) **Lateral geniculate nucleus:**
- Located in the thalamus.
 - Essential for conscious vision.
 - Primary recipient of retinal input.
- (2) Different morphological types of retinal ganglion cells project to different brain structures.
- Midget (parvocellular) ganglion cells project to the parvocellular layers of the LGN.
 - 80% of all ganglion cells are midget.
 - They have very small receptive fields and are slow at propagating action potentials.
 - Parasol (magnocellular) retinal ganglion cells project to the magnocellular layers of the LGN.
 - 10% of all ganglion cells are parasol.
 - They have larger receptive fields and support faster transmission of information.
- (3) In the optic chiasm, half of the axons from each eye cross to the contralateral hemisphere (w.r.t the eye of origin), such that the **left hemifield** is processed in the **right hemisphere**, and vice versa. Visual information is received upside down.

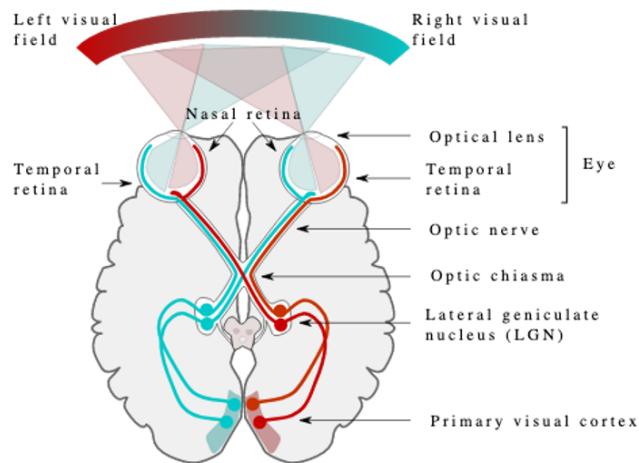


FIGURE 2.10. Optic chiasm.

- (4) Signals originating in each eye are transmitted in separate channels. In the LGN, information from each eye is processed in different layers; in V1, they are processed in different “columns”, thus giving rise to **ocular dominance columns**.

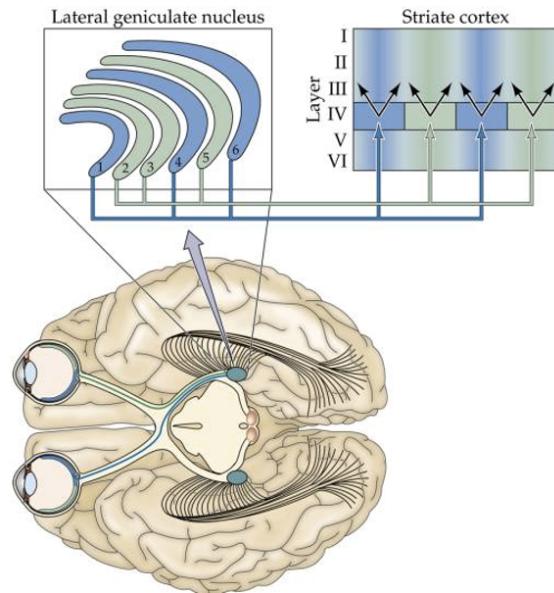


FIGURE 2.11. Layers in the LGN and columns in V1; layers 1, 4, and 6 receive contralateral projections.

2.3.4. Primary visual cortex.

- (1) The primary visual cortex (V1) contains neurons that respond selectively to bars oriented in specific orientations (i.e. **orientation-selective cells**).

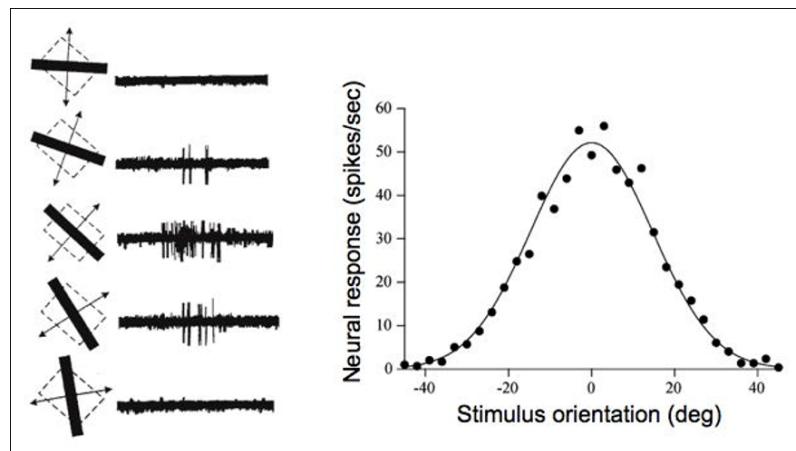


FIGURE 2.12. Orientation selective cells.

Extensive damage to V1 would most likely lead to blindness.

- (2) **Complex cells** found in V1 respond to lines anywhere in their receptive fields.

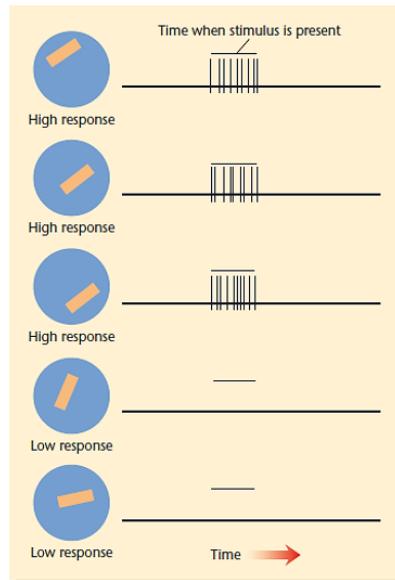


FIGURE 2.13. Response of complex cells.

Simple cells, on the other hand, have separate excitatory and inhibitory zones.

- (3) **Direction-selective cells** found in V1 are complex cells that respond preferentially to stimuli moving in a specific direction.

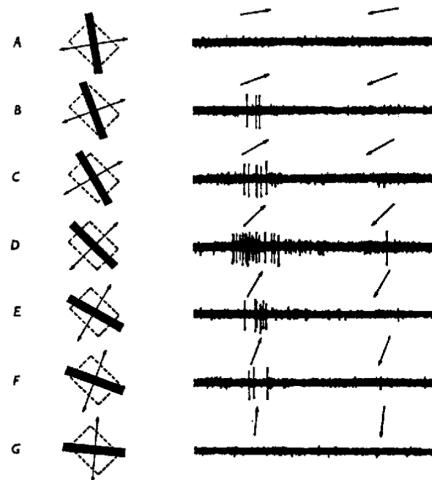


FIGURE 2.14. Direction selective cells.

2.3.5. Higher visual areas.

(1) **Sensitive/critical periods** are periods of time during the lifespan when experiences have a particularly strong and enduring effect.

- It ends with the onset of chemicals that inhibit axonal sprouting.
- Changes that occur during this period require both excitation and inhibition of some neurons.

For example, early lack of stimulation of one eye leads to synapses in the visual cortex becoming gradually unresponsive to input from that eye. Early lack of stimulation of both eyes causes cortical responses to become sluggish, but does not cause blindness.

(2) V1 is the source of two visual pathways:

- (a) The **dorsal/“where”/magnocellular pathway**, and
- (b) The **ventral/“what”/parvocellular pathway**.

(3) The dorsal pathway is involved in spatial and movement processing.

- Damage to the **middle temporal area (area MT)** produces **akinetopsia** (inability to see motion).
- Damage to **dorsal parietal areas** may produce **visuospatial neglect** (inability to pay attention to a part of space).

(4) The ventral pathway is involved in object recognition.

- Damage to the **inferior temporal cortex (area IT)** may produce **agnosia** (inability to recognize objects).
- Damage to the **fusiform gyrus** in area IT may produce **prosopagnosia** (a special case of agnosia with an inability to recognize faces).
 - Some neurons in the posterior face patches respond selectively to faces.
 - Some neurons in the middle face patches respond selectively to features of faces (e.g. pupils or hair).
 - Some neurons in the anterior face patches respond selectively to specific faces (i.e. a specific person) – known as *object invariance*.

2.4. Hermann Grid Illusion.

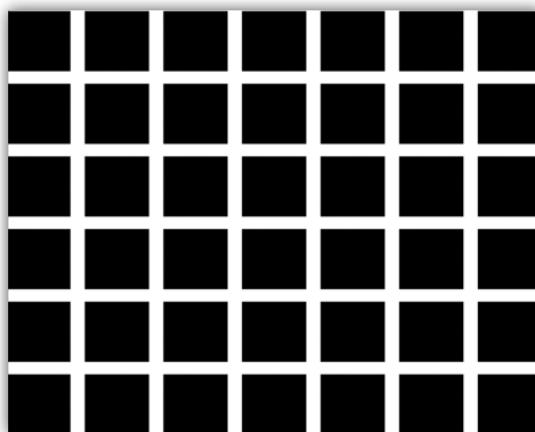


FIGURE 2.15. An image illustrating the Hermann grid illusion.

2.4.1. Baumgartner's hypothesis.

- (1) At the periphery:
 - Rods which have larger receptive fields are used.
 - The grey blobs are due to the *crossroads* appearing darker than the *paths*, because:
 - At the paths, the OFF-surround isn't firing fully, as part of their portion isn't 'illuminated' by the white background. However, their ON-center is fully firing.
 - At the crossorads, the OFF-surround is fully firing as they are completely 'illuminated' by the white background.
 - Our brains compare the two together, and assume that the paths are 'brighter' than the crossroads. Therefore, the crossroads have grey blobs.
- (2) At the fovea:
 - Cones which have smaller receptive fields are used.
 - Hence, the phenomenon is not observed as the ON-center OFF-surround are equally 'illuminated'.

2.4.2. Issues with Baumgartner's hypothesis.

- (1) The grid illusion is **size independent**.
- (2) Curvature of grids removes the illusion.
- (3) Arrangement of the grid is important; 45° rotation of the grid disrupts the illusion.
- (4) Arrangement of color is important if colored grids and lines are used.

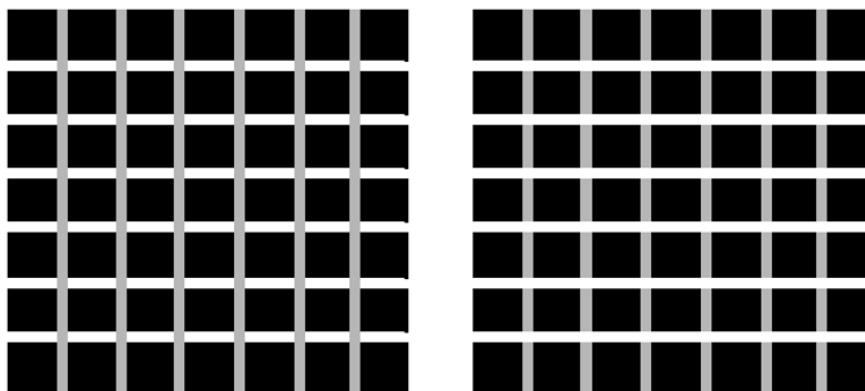


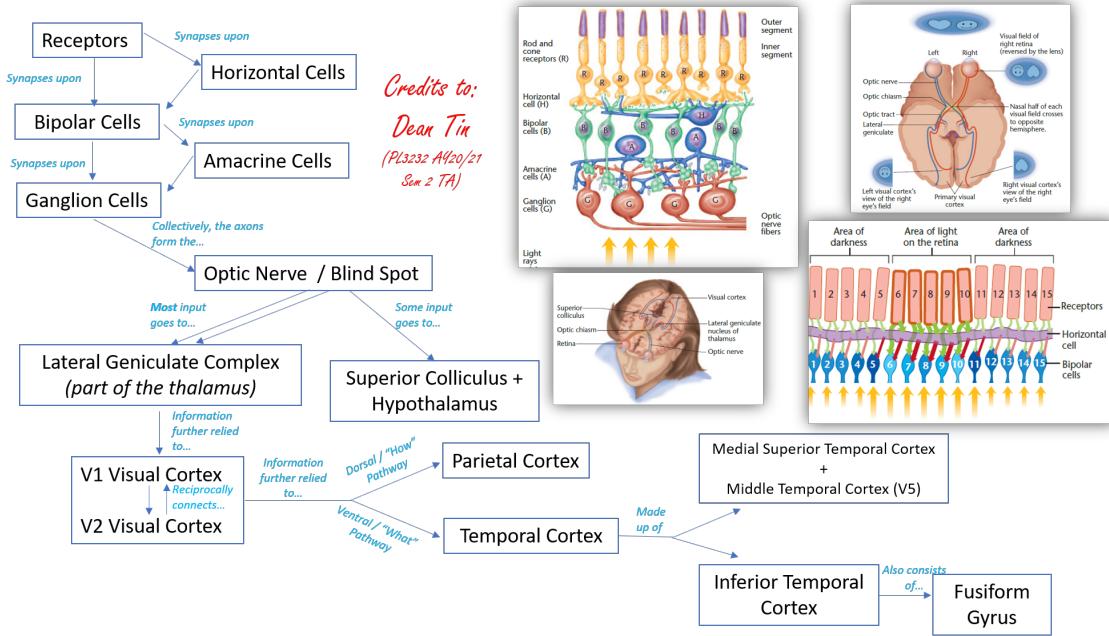
FIGURE 2.16. Difference in contrast of the lines can enhance the illusion, but only when lower contrast lines are in front.

- (5) **Isoluminance** disrupts the illusion.
- (6) Computer simulations on the illusion show a disparity between what we should expect and what we actually see.

2.4.3. Radiating edge hypothesis.

- (1) The short segments of white-black edges radiate 'darkness' on their dark side and 'lightness' on their light side.
- (2) The straighter a continuous edge, the stronger the radiation of its elemental segments.

2.4.4. Summary of vision.



2.5. Audition, Olfaction, and Taste.

2.5.1. Audition.

- (1) It is the sensation of periodic compressions of air, water, or other media.
- (2) Sounds can be described by three properties:
 - **Pitch:** determined by the frequency of sound waves.
 - As we age, we gradually lose the ability to sense higher frequencies due to exposure to loud noises.
 - **Loudness:** determined by the amplitude of sound waves.
 - **Timbre:** determined by secondary frequencies in the sound waves.
- (3) The ear has three subdivisions:
 - **Outer ear:**
 - **Pinna:**
 - * Alters reflection of sound waves, important for sound localization (along the vertical axis).
 - **Middle ear:**
 - **Tympanic membrane (eardrum):**
 - * Connects the outer and middle ear.
 - * Vibrates when struck by sound waves.
 - * Moves the 3 tiny bones of the middle ear.
 - 3 tiny bones:
 - * Amplify the movement of sound waves.
 - * Move the oval window that connects the middle and inner ear.

- **Eustachian tube:**
 - * Connects the middle ear to the mouth.
- **Inner ear:**
 - **Semicircular canals:**
 - * Three semicircles which mediate balance.
 - **Cochlea:**
 - * Snail-shaped structure which mediates audition.

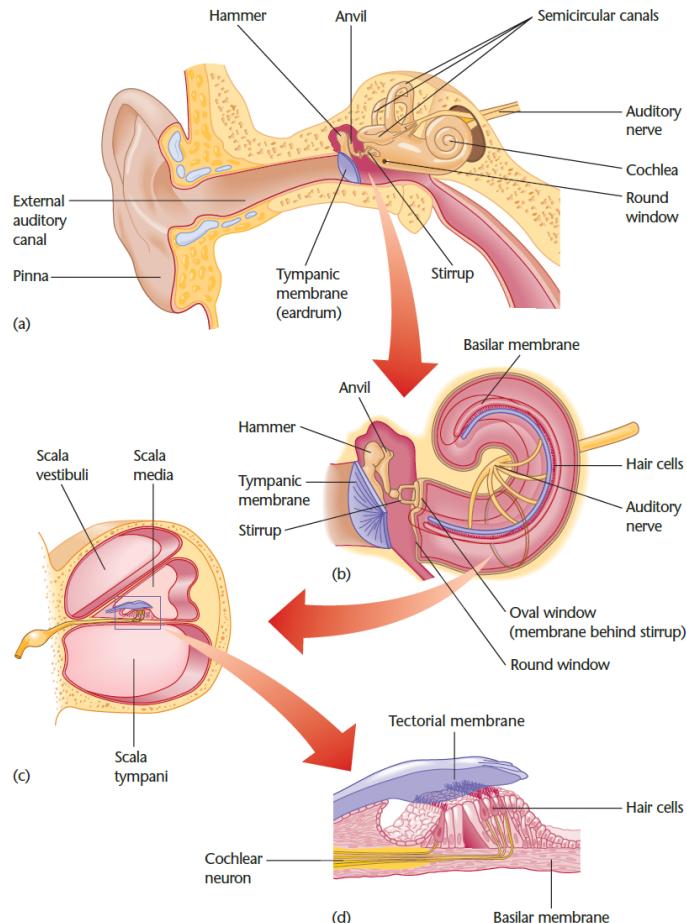


FIGURE 2.17. Structures of the ear.

2.5.2. Anatomy of the auditory system.

- (1) The **cochlea** is a snail-shaped structure that contains:
 - the **organ of Corti**, a structure that is formed by 2 membranes (tectorial and basilar membrane), and
 - **hair cells** (sensory neurons/auditory receptor cells) which are located on the basilar membrane.
- (2) **Mechanotransduction** by hair cells converts mechanical energy (due to fluid vibrations) into electrochemical energy (in the form of APs) by operating mechanically-gated K⁺ channels to open near the hairs of the cells.

Since the extracellular fluid around the tip has a higher concentration of K⁺ than the liquid in the base of the cell, the opening of the channels depolarizes the cell.

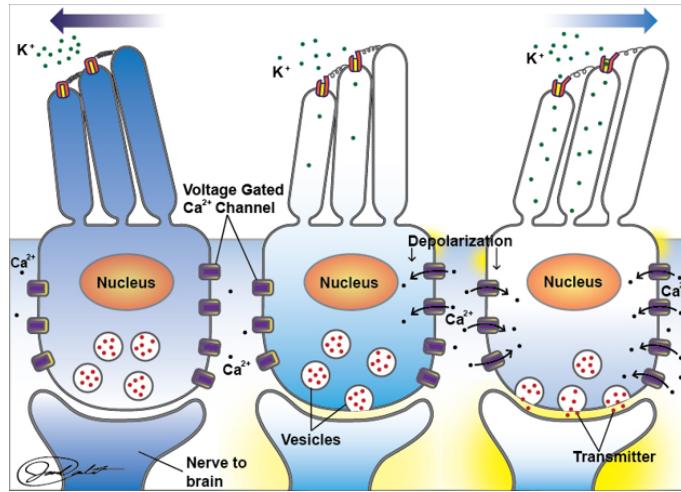


FIGURE 2.18. Mechanotransduction in hair cells.

- (3) Persons with hair cell damage can recover audition using **cochlear implants**, which stimulate the auditory nerve.

2.5.3. Auditory perception.

- (1) Auditory signals are processed by several subcortical structures, before reaching the primary auditory cortex in the temporal lobe.

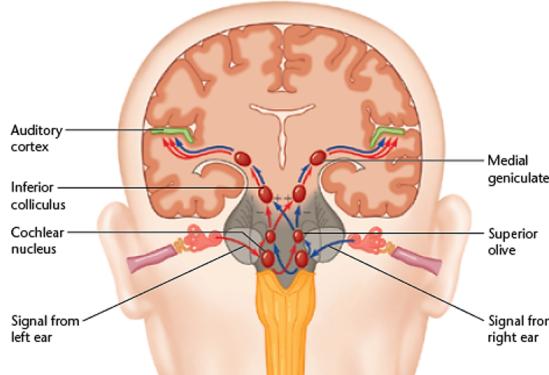


FIGURE 2.19. Auditory pathways.

- (2) Two theories help explain pitch perception:

- (a) **Place theory** states that different portions of the basilar membrane vibrate with different frequencies, selectively activating hair cells in that area.
- (b) **Frequency theory** states that the entire basilar membrane will vibrate in synchrony with a sound, causing auditory nerve axons to produce APs at the same frequency.

Place theory explains best perception of higher frequencies, while frequency theory explains best perception of low frequencies.

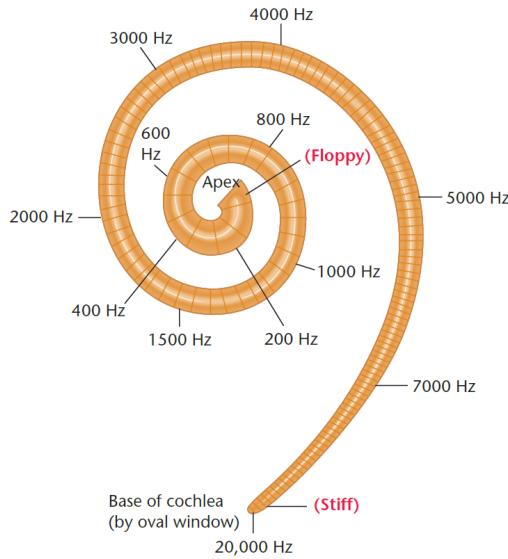


FIGURE 2.20. Illustration of place theory of pitch perception.

The **volley principle** (i.e. information from multiple neurons are combined) explains perception for very high frequencies (500 - 5000 Hz).

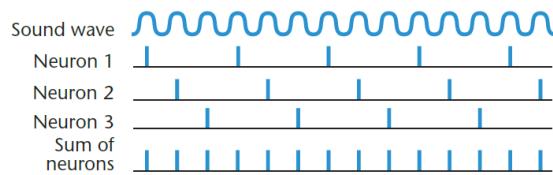


FIGURE 2.21. Illustration of the volley principle.

- (3) The auditory cortex is organized into primary, secondary, and tertiary areas. The **primary auditory cortex (A1)**:
 - is located in the superior temporal cortex.
 - has specialized pathways for identifying and locating sounds.
 - has a *tonotopic arrangement* (i.e. tones close to each other in terms of frequency are represented in topologically neighbouring regions in the brain).
 - is important for *auditory imagery*.
 - develops based on experience.

On the other hand, the **secondary auditory cortex** processes more complex sounds and auditory memory.

- (4) **Absolute/perfect pitch** is the ability to hear a note and identify its pitch.
 - It develops more commonly with early musical training and among individuals learning tonal languages.
 - These individuals have a larger auditory cortex, particularly the **Heschel's gyrus**.
- (5) Sounds can be localized either using **differences across both ears** in the horizontal axis, i.e.:
 - sound shadow (for high-frequency sounds),
 - phase difference (for frequencies up to 1500 Hz), or

- time of arrival (useful for sounds with sudden onset),
as well as by detecting different interference patterns in the vertical axis (by the pinna).

2.5.4. Taste.

- (1) **Taste** signals originate in the tongue's taste receptor cells, which have 5 receptor types (salty, sweet, sour, bitter, and umami) and send information to the **primary taste cortex** located in the **insula**.
- (2) **Taste adaptation** refers to receptors getting "fatigued" after repeated exposure to a stimulus. There is no **cross-adaptation**, i.e. other tastes are unaffected.
- (3) **Saltiness** and **sourness** are transduced directly by chemical stimuli (due to taste receptor's cell membrane's selective permeability to Na^+ and H^+).
Sweetness and **umami** (each taste has 2 types of receptors), as well as **bitterness** (has 25 types of receptors), have metabotropic receptors and trigger secondary messengers.
 - Bitterness is the most important taste from an evolutionary perspective, due to its association with toxicity.
- (4) **Labelled-line coding** uses a one-to-one correspondence between neural response and stimulus. **Population coding** uses a many-to-one relationship.

2.5.5. Smell.

- (1) **Smell** signals originate in the nose's olfactory receptor cells, which have hundreds of receptor types (one for each smell). This information converges on the olfactory bulb, located in the base of the frontal lobe.
 - Chemicals that smell similar excite neighbouring areas.

The olfactory bulb sends axons to the cerebral cortex, and it uses population coding (messages are coded by location) to detect a wide range of smells.

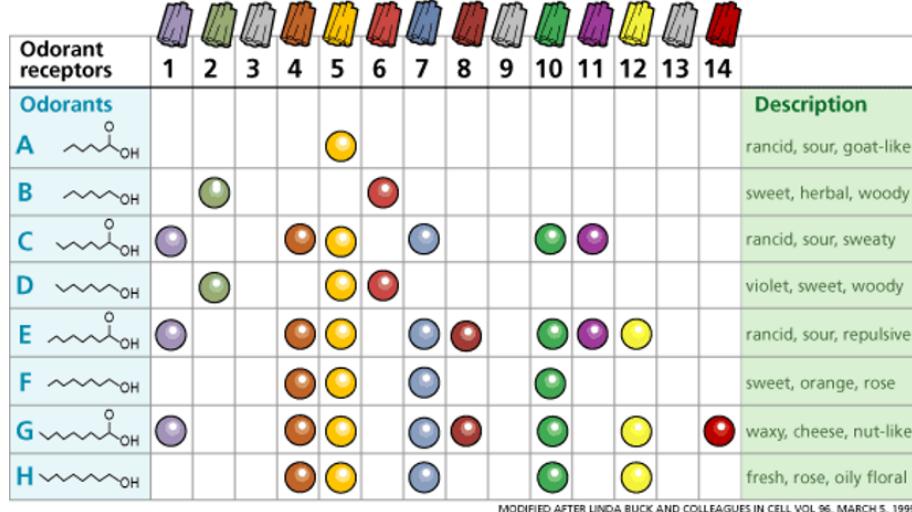


FIGURE 2.22. Olfactory stimuli do not vary along a continuum.

- (2) **Pheromones** are chemicals that affect the behavior of others from the same species unconsciously. The **vomeronasal organ (VNO)** is a set of receptors found in most mammals, located near the olfactory receptors, that are sensitive to pheromones. The evidence for their effects on humans is controversial.

- (3) **Synesthesia** is the experience of one sense in response to stimulation of a different sense.
It may be caused by:

- genetic factors,
- early experience, or
- axons from one cortical area branching into another area.

2.6. Sensation and Movement.

2.6.1. Mechanoreceptors.

- (1) We have four mechanosensory subsystems:

- The **vestibular system** detects the position and *acceleration* of our head, and adjusts the body accordingly. It consists of:

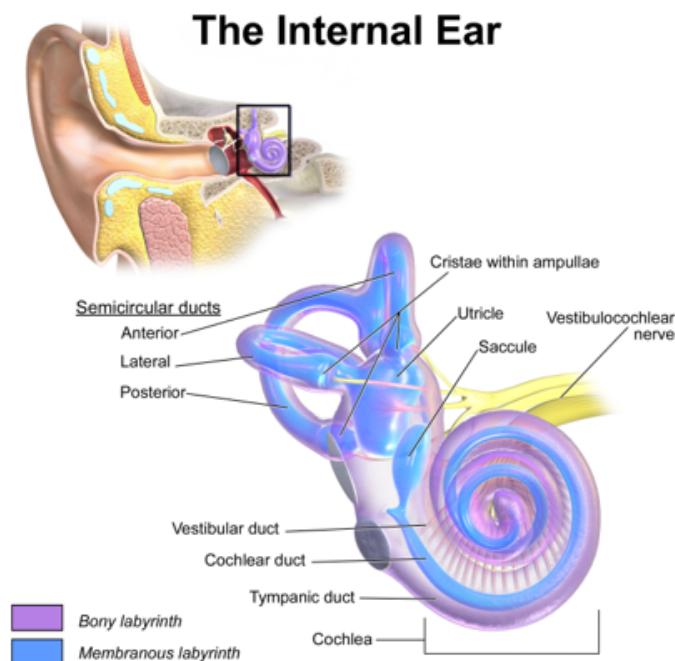


FIGURE 2.23. Structures of the internal ear.

- the **bony labyrinth** (which is filled with a fluid – *perilymph*)
 - * Contains the **utricle** (detects movement in the horizontal plane) and the **saccule** (detects movement in the vertical plane), which contains CaCO_3 particles that push against hair cells when the head tilts, leading to either depolarization or hyperpolarization, depending on the direction of their movement.
- the **membranous labyrinth** (suspended within the perilymph, contains another fluid called the *endolymph*).
- the **semicircular ducts** (anterior, lateral, and posterior) which are oriented to each other perpendicularly.
 - * They serve to detect the direction of head movement in the three different planes.
 - * They are sensitive only to acceleration.

- The **cutaneous/subcutaneous** (i.e. touch) system.
- The **proprioceptive** system.
- The **pain/temperature** system.

(2) There are four main types of mechanoreceptors in hairless mammalian skin:

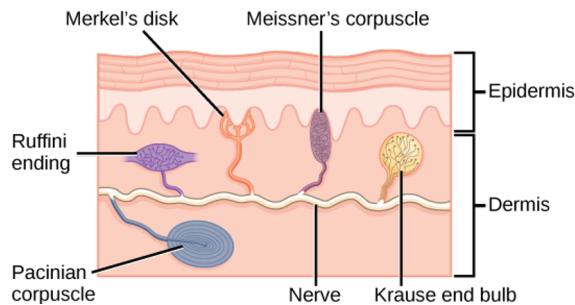


FIGURE 2.24. Mechanoreceptors in the skin.

- **Meissner's corpuscles:**

- Sensitive to light touch and movement.
- Sensitive to changes in texture.

- **Merkel's discs:**

- Unencapsulated nerve endings that respond to light touch.
- Small, well-defined receptive fields which are highly sensitive to edges.
- Their density differs throughout the body (e.g. we have 3-4 times more in the fingertips than in the forearm).

- **Ruffini endings:**

- Located in the deeper layers of the skin.
- Slow adapting and sensitive to sustained pressure.
- Sensitive to skin stretch, thus they are important for controlling finger position and movement.

- **Pacinian corpuscles:**

- Onion-like outer structure which resists gradual or constant pressure.
- Sudden or vibrating stimulus bends the membrane and increases the flow of sodium ions to trigger an action potential.

Receptor	Location	Responds to
Meissner's corpuscles	Hairless areas	Movement across the skin
Merkel's discs	Any skin area	Static touch
Ruffini endings	Any skin area	Skin stretch
Pacinian corpuscles	Any skin area	Vibration or sudden touch

(3) **Thermoreceptors** and **nociceptors** are bare nerve endings that sense temperature and pain.

- **Thermoception** is important to enable humans to regulate temperature, as both overheating and overcooling can be fatal.

- **Cold-sensitive neurons** respond to drops in temperature, adapt quickly, and show little response to constant, cold temperatures.
- **Heat-sensitive neurons** respond to *absolute temperature*.
- Chemicals can stimulate receptors for heat and cold, e.g. capsaicin and menthol.

- **Nociception:**

- Axons carrying pain information have little or no myelin, thus impulses travel relatively slowly.
- However, the brain processes pain information rapidly and motor responses are fast.
- Mild pain triggers the release of **glutamate** in the spinal cord (in the *substancia gelatinosa*).
- Stronger pain triggers the release of glutamate and several neuropeptides including **substance P** and **calcitonin gene-related peptide (CGRP)**.

2.6.2. Pathways to the central nervous system.

(1) Each spinal nerve in the body has a sensory component and a motor component that connects to a limited area of the body (a **dermatome**). Sensory information entering the spinal cord travel in well-defined and distinct pathways.

Ascending tracts carry sensory information from mechanoreceptors and other sensory receptors:

- (a) the **dorsal column-medial lemniscal pathway**: begins in the *dorsal root ganglia*, synapse in the *medulla*, runs up to the ventral posterior nuclear complex of the *thalamus*, where information is then transmitted to the *primary somatosensory cortex*.
- (b) the **anterolateral pathway**: begins in the *substancia gelatinosa*, run up to the ventral posterior nuclear complex of the *thalamus* through two separate spinothalamic tracts, where information is then transmitted to the *primary somatosensory cortex*.
- (c) the **spinocerebellar pathways**: process unconscious information (e.g. proprioception).

with parallel somatosensory representations maintained. Descending tracts carry motor information from the brain to the muscles:

- (a) **Pyramidal tracts** (conscious) include:

- **Corticospinal tracts:**

- Receive input from several areas of the cortex.
- Descend through the spinal cord to send signals to muscles throughout the body.

- **Corticobulbar tracts:**

- Arise from the lateral aspect of the primary motor cortex.
- Carry signals to the cranial nerves.

- (b) There are also four **extrapyramidal tracts** (unconscious).

- (2) Somatosensory cortex has a **somatotopic** arrangement (adjacent body parts occupy adjacent areas of the cortex), and the area dedicated to a region is proportional to the number of neurons originating from the area (i.e. cortical homunculus).
- Activation in the primary somatosensory cortex is necessary for conscious perceptions of touch.
 - The activity in this area corresponds to what a person is experiencing (rather than what is actually stimulating his/her receptors).
 - Damage to this area impairs body perceptions (e.g. difficulty localizing where one is being touched).

2.6.3. Control of movement.

- (1) Vertebrates have three kinds of muscle fibers: **smooth muscle**, **skeletal muscle**, and **cardiac muscle**.

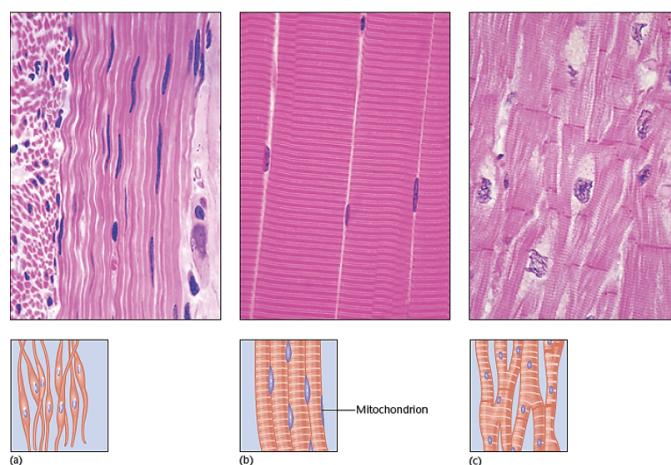


FIGURE 2.25. Types of muscles: (a) smooth muscle (b) skeletal muscle (c) cardiac muscle.

The synapse between a motor neuron and a muscle fiber is called the **neuromuscular junction**. Muscles only contract – **antagonistic sets** of muscles (i.e. *flexors* and *extensors*) are needed to move a body part back and forth.

- (2) **Proprioception** is a body's ability to perceive its own position in space – it is necessary for us to be able to perform precise movements. It can be conscious or unconscious, e.g. **reflexes** are a form of unconscious proprioception.

Proprioceptors are sensitive to the position and movement of the body.

- **Muscle proprioceptors** are used in muscle reflexes.
- **Golgi tendon organs** respond to increases in muscle tension, and protect the muscle from high levels of force.

- (3) **Central pattern generators** produce fixed sequences of behaviors with a fixed rhythm (in the absence of conscious rhythmic input). They originate from small neural networks in the spinal cord.

2.6.4. Brain mechanisms of movement.

- (1) Multiple regions in the cerebral cortex work in concert to produce complex, conscious movement. The **primary motor cortex** elicits movements.

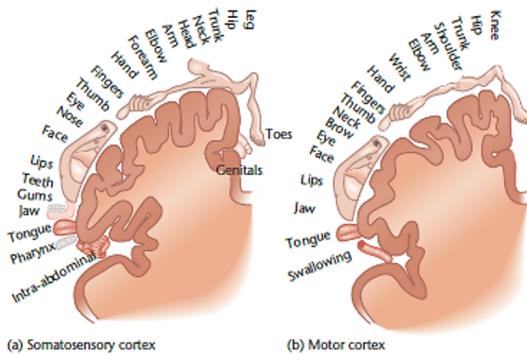


FIGURE 2.26. A comparison of the body maps in the somatosensory and motor cortices.

Other areas coordinate planning, spatial information, and expected outcomes of moving.

- **Posterior parietal cortex:**

- Monitors body position.
- Monitors motor planning and intention to move.
- Transforms information into motor commands.

- **Supplementary motor cortex:**

- Becomes active just prior to a movement.
- Involved in planning and organization of sequences of movements.
- Inhibits habitual movements.
- Corrects errors.

- **Premotor cortex:**

- Prepares to move.
- Guides movement using sensory information.

- **Inferior prefrontal cortex:**

- Involved in the halting of **prepotent responses**, thus is important for the control of impulsive behavior.
- This system is impaired in children with ADHD.

- (2) The **cerebellum** is critical for movements that require accurate aim and timing (i.e. balance and coordination). It also:

- responds to sensory information even in the absence of movement.
- responds strongly to violations of sensory information (e.g. reaching to touch something but not feeling it).

- (3) The **basal ganglia** are important for self-initiated behavior and learning new motor skills, but they do not directly produce any movement (they only coordinate any movement that occurs). Their dysfunction is implicated in a number of movement disorders (e.g. OCD and Tourette's syndrome).

- The **caudate** and **putamen** (together called the **striatum**) are the main *input* nuclei to the basal ganglia.

- The **globus pallidus** are the main *output* nuclei.

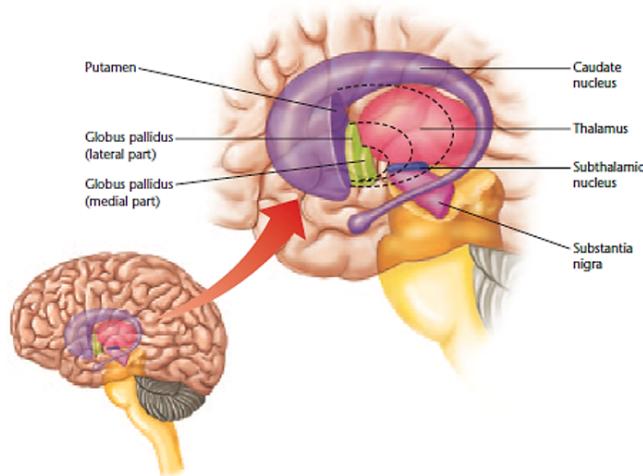


FIGURE 2.27. The basal ganglia.

In the **direct pathway**, the input inhibits the thalamus. Blocking this inhibition allows movement to occur. Activity in the **indirect pathway** inhibits unwanted or inappropriate competing movements. These two pathways have competing roles, and the balance of activity in these pathways allows for smooth movement and motor learning.

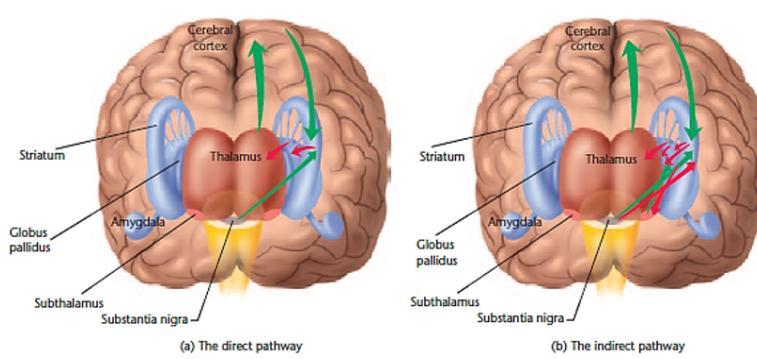


FIGURE 2.28. Direct and indirect pathways in the basal ganglia.