The Special Senses

Dr. Ali Ebneshahahidi
a) **Accessory structures** of the eye are those that are not directly related the sense of vision, but facilitate the physiology of the eyeballs.

- **Eyebrows** – to shade the eyes from sunlight and to prevent perspiration from reaching the eyes.

- **Eyelids** - to protect the eyes from foreign objects (e.g. dust particles) and to prevent desiccation (drying) of the eyes by lubricating fluid.

- **Conjunctiva** - a mucous membrane on the inner lining of eyelids, which produces lubricating and cleansing fluid for the surface of eye.
Surface anatomy of the eye

(a) Surface anatomy of the right eye

Eyebrow
Eyelid
Eyelashes
Site where conjunctiva merges with cornea
Palpebral fissure
Lateral commissure
Iris

Pupil
Sclera (covered by conjunctiva)
Lacrimal caruncle
Medial commissure

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Lacrimal gland - exocrine gland that secretes a dilute saline solution called tears for moistening the eyes. [Tears contain mucus, antibodies and antibacterial enzymes that protect the eye from infections. Emotional tears also contain enzymes that seem to help reduce stress levels].
Anatomy of the Eye

The wall of the eyeball consists of 3 layers of tissue:

• I) Fibrous Tunic:
  • - outermost layer, made of fibrous connective tissue with minimal blood vessels.
  • - contains 2 regions: sclera (a white area that extends from the back of the eye toward the front) and cornea (a transparent tissue in the front for allowing light to enter the eyeball).

• II) Vascular Tunic (also called uvea):
  • - middle layer, made of thin fibrous connective tissue that contains numerous blood vessels (capillaries).
(a) *Diagrammatic view*. The vitreous humor is illustrated only in the bottom part of the eyeball.
Also contains **choroids** (a pigmented membrane in the back to provide nutrition and to absorb light) and **iris** (to regulate the amount of light entering the eye by constriction or dilation)

Also includes specialized structures such as **ciliary body** (which regulates the shape of lens), **suspenory ligaments** (which attach the ciliary body to the lens).

Also includes the **Lens** (another transparent tissue that bends the light entering the eye), and **pupil** (an opening created by the actions of the iris where a large pupil is caused by a dilated iris, while a small pupil is created by a constricted iris).
(b) Photograph of the human eye.
III) **Sensory Tunic** (also called *retina*):
- innermost layer, made of specialized nerve tissue.
- contains 2 layers of tissue: an outer pigmented layer (which absorbs light and stores **vitamin A**) and an inner neural layer (that detects light using photoreceptors and sends nerve impulses to the occipital lobe of cerebrum through the optic nerves.
  
  - 2 types of photoreceptors are found on the neural layer: **Rods** (detect tones of visual images) and **cones** (detect colors). These sensory cells, after being stimulated by visual sensations, send nerve impulses through the optic nerve (Nerve II) to the occipital lobs of cerebrum.
## Layers of the eye

<table>
<thead>
<tr>
<th>Anterior portion:</th>
<th>Function:</th>
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<tbody>
<tr>
<td>Cornea</td>
<td>- Light transmission &amp; refraction</td>
</tr>
<tr>
<td>Ciliary body, Iris</td>
<td>- Accommodation, controls light intensity</td>
</tr>
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<table>
<thead>
<tr>
<th>Posterior portion:</th>
<th></th>
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<tbody>
<tr>
<td>Sclera (outer layer)</td>
<td>- protection</td>
</tr>
<tr>
<td>Choroids (middle layer)</td>
<td>- Blood supply, pigment prevents reflection</td>
</tr>
<tr>
<td>Retina (inner layer)</td>
<td>- photoreception, &amp; impulse transmission</td>
</tr>
</tbody>
</table>
Pathway of light:
Cornea ➔ Aqueous humor ➔ Lens ➔ Vitreous humor ➔ Retina.

(a) Diagrammatic view. The vitreous humor is illustrated only in the bottom part of the eyeball.
The eyes and vision:

- The eye is like a camera. The eyes diaphragm is the iris, which changes pupil aperture, regulating the amount of light entering.

- The curved cornea and the biconvex lens are like a cameras compound lens, refracting and converging light rays to form inverted images on the light – sensitive retina (film).

- The ciliary muscles change lens curvature for sharp focusing; in a camera, the lens moves back and forth.

Dynamics of vision:

- Light which bears the visual image crosses a series of transparent media (refractive) media where it is focused upon the retinal surface.
Refraction

- Light rays passing through the transparent media of different densities are bent (refraction). The denseness and curvature of the medium determines the degree of refraction.

- Refraction is necessary to form a small – sized inverted image on the retina (refractory media is the cornea and lens).

- The lens must thicken to focus on close objects.
Accommodation, Close, & Distant vision

- **Accommodation:** As the distant object moves closer, the image moves behind the retina to keep the image sharply on the retina, the lens accommodates.

- **Close vision:** Ciliary muscles contract, lens ligaments (suspensory) relax, and lens becomes rounder (more convex).

- **Distant vision:** Ciliary muscles relax, lens ligaments (suspensory) contract, lens becomes less convex (concave).

Note: With age, the lens hardens and is less able to accommodate. After age 55, accommodation is no longer possible (presbyopia), requiring corrective lenses for reading.
• **Pupil constriction:** During accommodation, the iris also constricts to narrow the pupil, permitting increased depth of focus. For very close objects external eye muscles move the eyeball inward (converge) to keep sharp focus.

• **Convergence:** The movement of each eye – ball is controlled by six eye muscles that allow the eyes to follow a moving object.
Extrinsic Eye Muscles

(a) Lateral view of the right eye

Superior oblique tendon
Superior oblique muscle
Superior rectus muscle
Lateral rectus muscle

Inferior rectus muscle
Inferior oblique muscle

(b) Superior view of the right eye

Trochlea
Superior oblique tendon
Superior oblique muscle
Superior rectus muscle

Axis of rotation of eye
Inferior rectus muscle
Medial rectus muscle
Lateral rectus muscle
Common tendinous ring
<table>
<thead>
<tr>
<th>Muscle</th>
<th>Innervation</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior rectus</td>
<td>Oculomotor</td>
<td>rotates eye up &amp; in</td>
</tr>
<tr>
<td>Inferior rectus</td>
<td>Oculomotor</td>
<td>rotates eye down &amp; in</td>
</tr>
<tr>
<td>Medial rectus</td>
<td>Oculomotor</td>
<td>rotates eye inwards</td>
</tr>
<tr>
<td>Lateral rectus</td>
<td>Abducens</td>
<td>rotates eye out</td>
</tr>
<tr>
<td>Superior oblique</td>
<td>Trochlear</td>
<td>rotates eye down &amp; out</td>
</tr>
<tr>
<td>Inferior oblique</td>
<td>Oculomotor</td>
<td>rotates eye up &amp; out</td>
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</tbody>
</table>
Near vision

1. Light rays from an object form a blurred image behind the retina.

2. The blurred image signals are sensed by the brain visual center, which activate midbrain motor center.

3. Corrective motor signals are send to accommodate lens.

4. Parasympathetic fibers release acetylcholine to contract the ciliary muscles, which relax the lens for sharp focusing, these nerves stimulate the iris to constrict the pupil.

5. Sympathetic fibers release nor epinephrine to stimulate the iris to dilate the pupil.
Photoreceptors of the Retina

- The retina contains rods and cones – photoreceptor neurons that synapse with bipolar cells.
- Rods are responsible for colorless vision in relatively dim light.
- Cones provide color vision and function in day light.
- A light sensitive pigment in rods (Rhodopsin) decomposes in the presence of light and triggers a complex series of reactions that initiate nerve impulses on the optic nerve.
- 3 sets of cones (Red, blue, green), provide color vision. Each set contains a different light – sensitive pigment, and each set is sensitive to a different wave length of light. The color perceived depends on which set or sets of cones are stimulated.
Microscopic anatomy of the retina

- Ganglion cells
- Bipolar cells
- Photoreceptors: Rod, Cone
- Axons of ganglion cells
- Amacrine cell
- Horizontal cell
- Pigmented layer of retina

(b) Cells of the neural layer of the retina
Physiology of vision

1. When light strikes the rods it causes photodissociation of Rhodopsin into retinene and opsin.
   - This bleaching reaction occurs maximally with a light wave length of 500 nm.
   - Photodissociation is caused by the conversion of the ll-cis form of retinene to the all – trans form that can not bind to opsin.

2. In the dark, more rhodopsin can be produced, and increased rhodopsin in the rods makes the eye more sensitive to light.
   - The rods provide black – and – white vision under conditions of low light intensity. At higher light intensity, the rods are bleached out and the cones provide color vision.
Photodissociation

1. Pigment synthesis:
   11-cis-retinal, derived from vitamin A, is combined with opsin to form rhodopsin.

2. Pigment bleaching:
   Light absorption by rhodopsin triggers a rapid series of steps in which retinal changes shape (11-cis to all-trans) and eventually releases from opsin.

3. Pigment regeneration:
   Enzymes slowly convert all-trans-retinal to its 11-cis form in cells of the pigmented layer; requires ATP.
3. In the dark, a constant movement of Na\(^+\) into the rods produces what is know as a "dark current".

In the dark, rhodopsin (R) molecules are stable, signaling Na\(^+\) channels to stay open. Inflow of Na\(^+\) depolarizes the rods and their synapses. This activates the inhibitory bipolar cells, which exert inhibition over the G-cells (Ganglion cells), thus G-cells are quiet in the dark.
Signal transmission in the retina

1. cGMP-gated channels open, allowing cation influx. Photoreceptor depolarizes.

2. Voltage-gated Ca\(^{2+}\) channels open in synaptic terminals.

3. Neurotransmitter is released continuously.


5. Hyperpolarization closes voltage-gated Ca\(^{2+}\) channels, inhibiting neurotransmitter release.

6. No EPSPs occur in ganglion cell.

7. No action potentials occur along the optic nerve.

Below, we look at a tiny column of retina. The outer segment of the rod, closest to the back of the eye and farthest from the incoming light, is at the top.
4. In the light, decomposition of R molecules signal the Na\(^+\) channels to close. This hyperpolarizes the rods and their synapses, leading to inhibition of BP-cells. Inhibited BP-cells allow increased activity in the G-cells and their axons informing the brain cells of the presence of light.
Signal transmission in the retina

Below, we look at a tiny column of retina. The outer segment of the rod, closest to the back of the eye and farthest from the incoming light, is at the top.

1. cGMP-gated channels close, so cation influx stops. Photoreceptor hyperpolarizes.

2. Voltage-gated Ca\(^{2+}\) channels close in synaptic terminals.

3. No neurotransmitter is released.

4. Lack of IPSPs in bipolar cell results in depolarization.

5. Depolarization opens voltage-gated Ca\(^{2+}\) channels; neurotransmitter is released.

6. EPSPs occur in ganglion cell.

7. Action potentials propagate along the optic nerve.
Visual Acuity: Retinal fovea centralis

- The fovea centralis contains only cones; more peripheral parts of the retina contain both cones and rods.
- Each cones in the fovea synapses with one bipolar cell, which in turn synapse with one ganglion cell.
- As a result of this 1:1 ratio of cones to bipolar cells, visual acuity is high in the fovea but sensitivity to low light levels is lower than in other regions of the retina.
Neural processing of visual information

- Photoreceptor neural (Rods & cones), transmit impulses to bipolar cells, which in turn send signals to Ganglion cells (some bipolar cells are inhibitory).

- Visual fields: The right half of the visual field is projected to the left half of the retina of each eye.
  
  - a. The left half of the left retina sends fibers to the left lateral Geniculate body of the thalamus.
  
  - b. The left half of the Right retina also sends fibers to the left lateral geniculate body. This is because these fibers decussate in the optic chiasma.
(a) The visual fields of the two eyes overlap considerably. Note that fibers from the lateral portion of each retinal field do not cross at the optic chiasma.
The left lateral geniculate body thus receives input from the left half of the retina of both eyes, corresponding to the right half of the visual field, the right lateral geniculate receives information about the left half of the visual field.
• **Ganglion cells** (axon) form the optic verve fibers which converge in the optic disc where they exit the eye forming the optic nerve.

• The inner fibers of each eye (medial fibers) decussate at the optic chiasma, the temporal fibers travel on the same side (ipsilateral).

• The direct crossed fibers then synapse in the geniculate body and are called **optic tracts**.

• A small number of fibers synapse in the **superior quadrigeminal** bodies and control pupillary reflexes.

• From the lateral genticulate body a diverging bundle of fibers (**optic radiation**) terminate in the occipital lobe where vision reaches consciousness, (**primary visual cortex**).

• Other impulses go to the brain stem for various visual reflex.
(a) The visual fields of the two eyes overlap considerably. Note that fibers from the lateral portion of each retinal field do not cross at the optic chiasma.
- From the primary visual cortex (pvc), visual signals follow along serial and parallel pathways to higher visual areas, in the occipital, parietal, and temporal cortex. Temporal pathway involves color and form perception, while parietal pathway analyze motion.

- Neurons in the pvc do not respond to illuminated spots but to features of stimuli, such as lines, edges and bars.

- Cells responding to stationary stimuli are called simple cells.

- Cells responding to more complex stimuli such as moving bars are called complex cells. Complex cells receive input from simple cells while sending output to other cortical or sub-cortical centers.
Simple and complex cells responding to a particular orientation are arranged in orientation columns running perpendicular to the cortical surface. The orientation columns are placed side by side across the cortex in such a way that those receiving input from one eye alternate with those connected to the other eye (ocular dominance columns).

<table>
<thead>
<tr>
<th>Stimulus pattern (portion of receptive field illuminated)</th>
<th>Response of on-center ganglion cell during period of light stimulus</th>
<th>Response of off-center ganglion cell during period of light stimulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>No illumination or diffuse illumination (basal rate)</td>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
</tr>
<tr>
<td>Center illuminated</td>
<td><img src="image3.png" alt="Graph" /></td>
<td><img src="image4.png" alt="Graph" /></td>
</tr>
<tr>
<td>Surround illuminated</td>
<td><img src="image5.png" alt="Graph" /></td>
<td><img src="image6.png" alt="Graph" /></td>
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</table>
Stereoscopic Vision

- Stereoscopic vision provides perception of distance and depth.
- Stereoscopic vision occurs because of the formation of two slightly different retinal images that the brain superimposes and intercepts as one image in three dimensions.
- Note: A one–eyed person uses relative sizes and positions of familiar objects to judge distance and depth.
Sense Of Hearing

- a) The gross anatomy of the human ear includes the outer ear (consists of auricle and external auditory meatus), middle ear (consists of tympanic membrane and auditory ossicles [malleus, incus, and stapes] and inner ear (consists of cochlea, 3 semicircular canals, and the vestibulocochlear nerve).

- b) The outer ear is responsible for transferring sound waves from the environment to the middle ear.

- c) The middle ear is responsible for amplifying sound waves into strong signals for the hearing receptors to detect.

- d) The inner ear is responsible for using mechanoreceptors to detect stimuli for hearing (in cochlea) and equilibrium (in semicircular canals), and send the nerve impulses through the vestibulocochlear nerve (Nerve VIII) to the brain.
- e) the middle ear also contains the **Eustachian tube** (auditory tube) that connects with the pharynx for equalizing air pressure in the skull.
External ear:
• Auricle (pinna): collects and directs sound waves to move the tympanic membrane.
• External auditory canal (meatus): leads sound waves from auricle to tympanic membrane.
Function: collecting and channeling sound waves into the ear canal.

Middle ear:
• Tympanic membrane: elastic structure which vibrates with sound waves. It is connected with auditory ossicles; 3 small bones – malleus, incus, and stapes which conduct vibrations to oval window of inner ear.
• Tympanic cavity: air spaces within temporal bone containing middle ear structures.
• Eustachian tube: communicates middle ear with pharynx.
• Muscle: tensor tympani stapedius protect inner ear from loud sounds.
Function: conduct and amplifies vibrations through the action of 3 bones.
(b) Middle and internal ear
**Internal ear:**

Osseous labyrinth: cavity within temporal bone shaped like the membranous labyrinth.
Membranous labyrinth: series of delicate channels containing endolymph / receptors.
Perilymph: fluid between osseous and membranous labyrinth. Leads sound to cochlea.
Endolymph: fluid within membranous labyrinth. Its movement stimulates hair cells (stereocilia).
Vestibule: portion of labyrinth containing cristae and maculae (head position, movement).
Cochlea: snail – like region containing sound receptors (cochlear organ). It is involved in sound wave transduction.
• Sound waves are characterized by frequency (cycles / sec or Hertz) and amplitude.
• Sound frequency = Pitch
• Amplitude = Loudness or intensity
• The ears outer, middle, and inner parts perform the functions of collecting, amplifying and transducing sound energy, respectively.

• The outer ears pinna and ear canal funnel sound waves onto the eardrum, causing it to vibrate.

• The ear – drum vibration is amplified 20 - fold through the lever action of the middle ears ossicles (malleus, Incus, stapes), and differential vibrating surfaces of the eardrum and the inner ears oval window.

• Stapes movement displaces the oval window and subsequently the basilar membrane of the inner ears cochlea, generating frequency - dependent traveling waves in the cochlea.

• The hair cells of the cochlea transduce sound waves into nerve impulse.
Inner ear
Sound transmission in the cochlea

The basilar membrane supporting the organ of corti runs along the cochlea's length, dividing it into 2 chambers: an upper scala vestibule and a lower scala tympani. A thin membrane running above the organ of corti creates a middle chamber, the scala media.

- The vestibule and tympanic chambers are filled with perilymph fluid, and communicate at the apex.
The medial chamber contains endolymph, which bathes the organ of corti and its hair cells. The oval and round windows at the 2 ends of the perilymph respectively absorb and release the sound waves and maintain perilymph in a compressed state.
- Cochlear hair cells are innervated by auditory fibers.
- Oval window vibration sets up traveling waves in the perilymph and endolymph, which causes the basilar membrane to vibrate.
- The vibration deforms the stereocilia on hair cells, resulting in receptor potentials that are synaptically transmitted to the auditory nerve fibers, triggering nerve impulses.
① Sound waves vibrate the tympanic membrane.
② Auditory ossicles vibrate. Pressure is amplified.
③ Pressure waves created by the stapes pushing on the oval window move through fluid in the scala vestibuli.
④a Sounds with frequencies below hearing travel through the helicotrema and do not excite hair cells.
④b Sounds in the hearing range go through the cochlear duct, vibrating the basilar membrane and deflecting hairs on inner hair cells.
• The organ of corti consists of the pillar of corti and hair cells that are located on the supporting cells of the basilar membrane.

• The middle – ear ossicles vibrate the cochlea's oval window.

• This sets up traveling waves in the perilymph of the cochlea vibrating the basilar membrane.

• High Hz sounds occurs at the cochlea's base, vibrating the narrow stiff basilar membrane of the basal cochlea.

• Low $H_Z$ sounds shift toward the apical cochlea, vibrating its wide, loose membrane.

• The basilar membrane vibration induce receptor potentials in the hair cells of the corresponding cochlear region.
The Hair cells act as true auditory receptors, and make synaptic contact with auditory nerve terminals.

Auditory fibers from different cochlear regions converge to form the auditory nerve, along with the vestibular nerve (cranial nerve VIII).

Auditory fibers of the cranial nerve VIII ascend to medulla oblongata, midbrain, and thalamus and are interpreted in the temporal lobes of the cerebrum.

Note: from thalamus, nerve fibers project to the auditory cortex of the temporal lobe, some auditory cortex neurons respond to high tones, some to low tones.

* In human, these auditory areas communicate with higher order cortical areas serving in language and speech functions.
Steps in the generation of sensory impulses from the ear

1. Sound waves enter the external auditory meatus.

2. Waves of changing pressure causes the tympanic membrane to vibrations coming from sound wave source.

3. Auditory ossicles amplify and transmit vibrations to the and of the stapes.

4. Movement of the stapes at the oval window transmit vibrations to the perilymph in the scala vestibule.

5. Vibrations pass through the vestibular membrane and enter the endolymph of the cochlear duct.

6. Different frequencies of vibration in endolymph move specific regions of the basilar membrane, thus stimulating specific sets of receptors cells (hair cells).
7. As receptor cell becomes depolarized; its membrane become more permeable to Ca$^{++}$ ions.

8. In the presence of Ca$^{++}$ ions, vesicles at the base of receptors cell release neurotransmitter.

9. Neurotransmitter stimulates the ends of nearby sensory neurons.

10. Sensory impulses are triggered on fibers of the cochlear branch of the vestibulocochlear nerve.

11. Auditory impulses travel into medulla oblongata, midbrain, and thalamus, and are interpreted in the temporal lobes of the cerebrum.
Physiology of sound processing & reception

Sound collected by pinna $\rightarrow$ transported through external auditory meatus $\rightarrow$ sets tympanic membrane in motion $\rightarrow$ vibration of malleus $\rightarrow$ incus $\rightarrow$ stapes $\rightarrow$ vibration of oval window $\rightarrow$ fluid wave formed by vibration of oval window travels $\rightarrow$ scala vestibule $\rightarrow$ scala tympani $\rightarrow$ sets basilar layer in motion $\rightarrow$ Different portions vibrate according to pitch $\rightarrow$ hair cells bend against tectorial membrane $\rightarrow$ Action potential $\rightarrow$ vestibulocochlear nerve $\rightarrow$ medulla oblongata $\rightarrow$ midbrain $\rightarrow$ thalamus $\rightarrow$ temporal lobes of cerebrum.
Sense of equilibrium

- a) Detected by mechanoreceptors in the semicircular canals to help maintain body posture and body stability.

- b) Nerve impulses generated by the receptors in semicircular canals is transmitted by the vestibular nerve to Nerve VIII, and the signals will be processed by the brain.

The inner ears vestibular apparatus detects changes in the heads (and body) position in space, signaling the brain motor centers to adjust posture and maintain balance.
Equilibrium

1) 3 **semicircular canals**, which respond to rotational acceleration, in head motion (dynamic balance).

- Vestibular apparatus

2) **saccule** and **utricle** (macular organs), which Respond to head tilting and linear acceleration (static balance).

- Note: saccule and utricle are also know as the **otolith** organs, covered by a gelatinous layer containing small calcite crystals (otoliths). The otoliths are covered by a fluid.
Linear acceleration (static balance)

1. The maculae are the sensory organs in both the saccule and the utricle.

2. Each macula consists of Hair cells covered by a gelatinous layer containing small calcite crystals (otoliths). The otoliths are covered by a fluid.

3. Horizontal or vertical acceleration of the head in space exerts a stronger pull on the otoliths, which are denser than the surrounding fluid.

4. This causes the otoliths to displace the stereocilia of the Hair cells and change their receptor potential (bending stereocilia).

5. This will stimulate the fibers of the vestibular nerve (which are attached to the Hair cells) to increase their nerve impulses according to the intensity of displacement.
Macula

Macula of utricle
Macula of saccule
Kinocilium
Stereocilia
Otoliths
Otolith membrane

(a)

Vestibular nerve fibers
Supporting cells
Hair cells

Rotational acceleration (dynamic balance)

- The **semicircular canals** are fluid–filled tubes. During any rotational movement of the head at least one canal will be active.

- Each canal has an **ampulla**, containing its sensory organ (**crista ampullaris**). The crista ampullaris contains **hair cells** whose stereocilia are embedded in the gelatinous cupula.

- When the head begins to rotate in a particular direction, the canal fluid initially lags behind, which shears the **cupula** (which is moving with the canal wall).

- This causes the stereocilia to bend in the opposite direction.

- This activates the Hair cells, causing the **vestibular nerve** fibers of cranial nerve VIII to increase its signals to the brain to initiate motor reflexes in the opposite direction to keep balance.
(a) Anatomy of a crista ampullaris in a semicircular canal

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Vestibulospinal reflexes

- The vestibular apparatus senses positional changes, and send impulses to brain via the vestibulocochlear nerve.

- In the medulla, the vestibular nuclei; receive these signals and send them to the cerebellum.

- The cerebellum issues appropriate directions to the vestibular nuclei; which signal the midbrain motor centers to execute proper reflex movements of the head, and eye muscles.

- These reflexes help maintain a steady image of the surrounding objects on retina. The vestibule nuclei also signal the spinal motor nuclei to activate the appropriate postural muscles. These reflexes help maintain balance.

- Note: spinning and then stopping abruptly can cause oscillatory movements of the eye (Nystagmus).
Input: Information about the body’s position in space comes from three main sources and is fed into two major processing areas in the central nervous system.

Vestibular receptors

Visual receptors

Somatic receptors (skin, muscle and joints)

Cerebellum

Vestibular nuclei (brain stem)

Central nervous system processing

Oculomotor control (cranial nerve nuclei III, IV, VI) (eye movements)

Spinal motor control (cranial nerve XI nuclei and vestibulospinal tracts) (neck, limb, and trunk movements)

Output: Responses by the central nervous system provide fast reflexive control of the muscles serving the eyes, neck, limbs, and trunk.