

Equilibrioception: Mastering Your Inner Sense of Balance

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Balance skill development in children

Sense of balance or equilibrioception is one of the physiological senses related to balance. It helps prevent humans and animals from falling over when standing or moving. Balance is the result of a number of body systems working together: the eyes (visual system), ears (vestibular system) and the body's sense of where it is in space (proprioception) ideally need to be intact. The vestibular system, the region of the inner ear where three semicircular canals converge, works with the visual system to keep objects in focus when the head is moving. This is called the vestibulo-ocular reflex (VOR). The balance system works with the visual and skeletal systems (the muscles and joints and their sensors) to maintain orientation or balance. Visual signals sent to the brain about the body's position in relation to its surroundings are processed by the brain and compared to information from the vestibular, visual and skeletal systems.



Balance training

Vestibular system

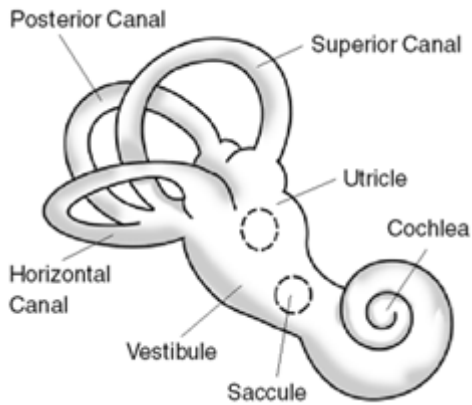
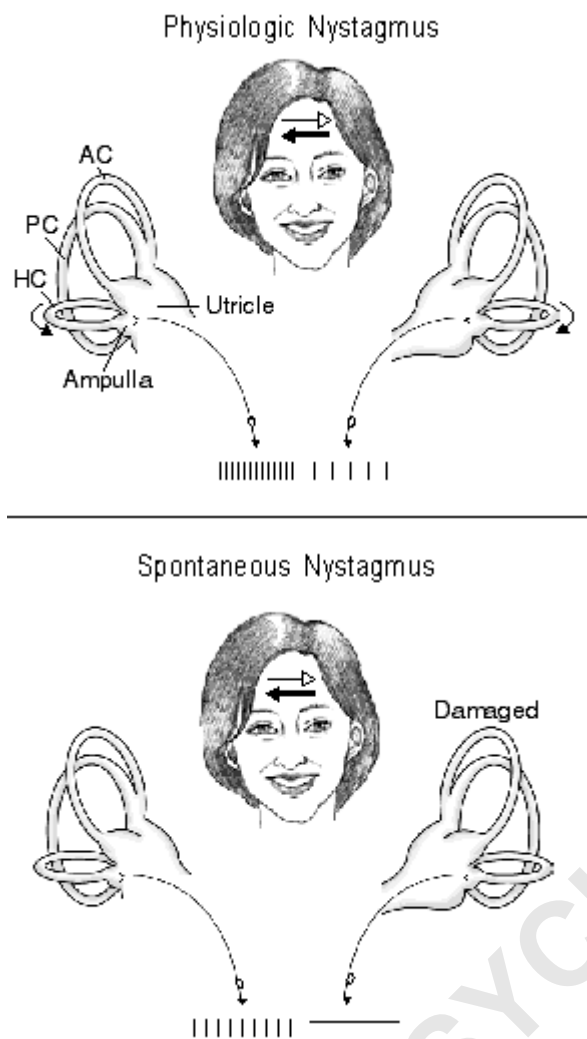


Diagram of vestibular system

In the vestibular system, equilibrioception is determined by the level of a fluid called endolymph in the labyrinth, a complex set of tubing in the inner ear.

Dysfunction



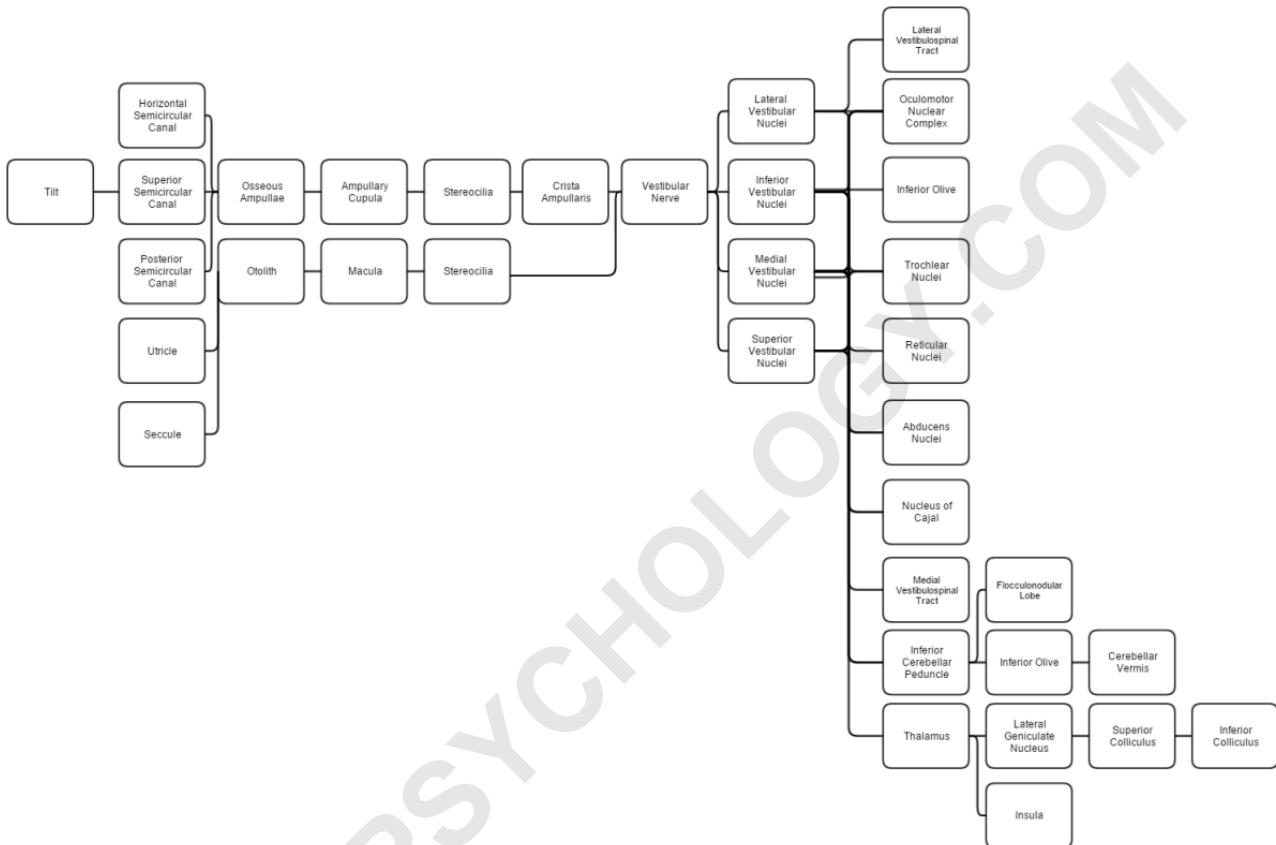
This figure shows nerve activity associated with rotational-induced physiologic nystagmus and spontaneous nystagmus resulting from a lesion of one labyrinth. Thin straight arrows - direction of slow components; thick straight arrows - direction of fast components; curved arrows - direction of endolymph flow in the horizontal semicircular canals: AC - anterior canal, PC - posterior canal, HC - horizontal canal.

When the sense of balance is interrupted it causes dizziness, disorientation and nausea. Balance can be upset by Ménière's disease, superior canal dehiscence syndrome, an inner ear infection, by a bad common cold affecting the head or a number of other medical conditions including but not limited to vertigo. It can also be temporarily disturbed by quick or prolonged acceleration, for example riding on a merry-go-round. Blows can also affect equilibrioception, especially those to the side of the head or directly to the ear.

Most astronauts find that their sense of balance is impaired when in orbit because they are in a

constant state of weightlessness. This causes a form of motion sickness called space adaptation syndrome.

System overview



This diagram linearly (unless otherwise mentioned) tracks the projections of all known structures that allow for balance and acceleration to their relevant endpoints in the human brain.

This overview also explains acceleration as its processes are interconnected with balance.

Mechanical

There are 5 sensory organs innervated by the vestibular nerve; 3 semicircular canals (HSCC, SSCC, PSCC) and 2 otolith organs. Each semicircular canal (SSC) is a thin tube that thickens briefly (2x thin diameter), at a point called osseous ampullae. At their center-base each contains an ampullary cupula. The cupula is a gelatin bulb connected to stereocilia, affected by the relative movement of the endolymph it is bathed in. Since the cupula is part of the bony labyrinth it rotates along with actual head movement unable to cause stimulation by itself; that is, if endolymph was

not present, movement could not be detected. Endolymph follows the rotation of the canal, however, due to inertia lags behind initially, which bends and activates the cupula. After any extended rotation the endolymph catches up to the canal and the cupula returns to its upright position and resets. When extended rotation ceases, however, endolymph continues, (due to inertia) which bends and activates the cupula.

Pilots doing long banked turns begin to feel upright (no longer turning) as endolymph matches canal rotation; once the pilot exits the turn the cupula is once again stimulated, causing the feeling of turning the other way, rather than flying straight and level.

Stereocilia bend causing chemical reactions in the crista ampullaris they surround (cristae are at cilia tips); this reaction creates an action potential carried by the vestibular nerve.

The HSCC handles head rotations about a vertical axis (the neck), SSCC handles head movement about a lateral axis, PSCC handles head rotation about a rostral-caudal axis. E.g. HSCC: looking side to side; SSCC: head to shoulder; PSCC: nodding. SCC sends adaptive signals, unlike the otolith organs whose signals does not adapt over time.

A shift in the otolithic membrane that stimulates the cilia is considered the state of the body until the cilia are once again stimulated. E.g. lying down stimulates cilia and standing up stimulates cilia, however, for the time spent lying the signal that you are lying remains active, even though the membrane resets.

Otolithic organs have a thick, heavy gelatin membrane that, due to inertia (like endolymph), lags behind and continues ahead past the macula it overlays, bending and activating the contained cilia.

Utricle responds to linear accelerations and head-tilts in the horizontal plane (head to shoulder), whereas saccule responds to linear accelerations and head-tilts in the vertical plane (up and down). Otolithic organs update the brain on the head-location when not moving; SCC update during movement.

Kinocilium are the longest stereocilia and are positioned (one per 40-70 regular cilia) in the center of the bundle. If stereocilia go towards kinocilium depolarization occurs causing more neurotransmitter, and more vestibular nerve firings as compared to when stereocilia tilt away from kinocilium (hyperpolarization, less neurotransmitter, less firing).

Neural

First order vestibular nuclei (VN) project to IVN, MVN, and SVN.

The inferior cerebellar peduncle is the largest center through which balance info passes. It is the area of integration between proprioceptive, and vestibular inputs to aid in unconscious

maintenance of balance and posture.

Inferior olive aids in complex motor tasks by encoding coordinating timing sensory info; this is decoded and acted upon in the cerebellum.

Cerebellar vermis has 3 main parts: vestibulocerebellum (eye movements regulated by the integration of visual info provided by the superior colliculus and balance info), spinocerebellum, and cerebrocerebellum (plans, times, and initiates movement after evaluating sensory input from, primarily, motor cortex areas, via pons and cerebellar dentate nucleus. It outputs to thalamus, motor cortex areas, and red nucleus).

Flocculonodular lobe is a cerebellar lobe that helps maintain body equilibrium by modifying muscle tone (continuous and passive muscle contractions).

MVN and IVN are in the medulla, LVN and SVN are smaller and in pons. SVN, MVN, and IVN ascend within medial longitudinal fasciculus (MLF). LVN descend the spinal cord within the lateral vestibulospinal tract and end at sacrum. MVN also descend the spinal cord, within the medial vestibulospinal tract, ending at lumbar 1.

Thalamic reticular nucleus distributes info to various other thalamic nuclei, regulating the flow of info. It is speculatively able to stop signals, ending transmission of unimportant info. The thalamus relays info between pons (cerebellum link), motor cortices, and insula.

Insula is also heavily connected to motor cortices; insula is likely where balance is likely brought into perception.

The oculomotor nuclear complex refers to fibers going to tegmentum (eye movement), red nucleus (gait (natural limb movement)), substantia nigra (reward), and cerebral peduncle (motor relay). Nucleus of Cajal are one of the named oculomotor nuclei, they are involved in eye movements and reflex gaze coordination.

Abducens solely innervates the lateral rectus muscle of the eye, moving the eye with trochlear. Trochlear solely innervates the superior oblique muscle of the eye. Together, trochlear and abducens contract and relax to simultaneously direct the pupil towards an angle and depress the globe on the opposite side of the eye (e.g. looking down directs the pupil down and depresses (towards the brain) the top of the globe). The pupil is not only directed but often rotated by these muscles. (See visual system)

The thalamus and superior colliculus are connected via lateral geniculate nucleus. Superior colliculus (SC) is the topographical map for balance and quick orienting movements with primarily visual inputs. SC integrates multiple senses.

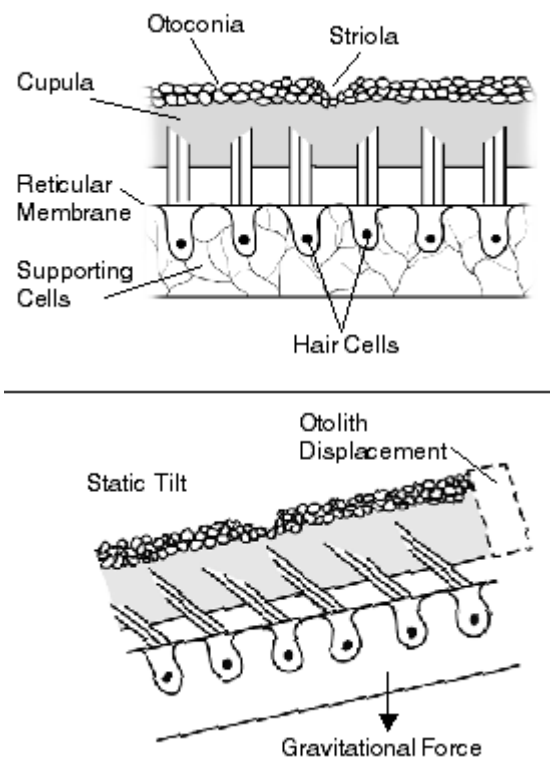


Illustration of the flow of fluid in the ear, which in turn causes displacement of the top portion of the hair cells that are embedded in the jelly-like cupula. Also shows the utricle and saccule organs that are responsible for detecting linear acceleration, or movement in a straight line.

Other animals

Some animals have better equilibrioception than humans, for example a cat uses its inner ear and tail to walk on a thin fence.

Equilibrioception in many marine animals is done with an entirely different organ, the statocyst, which detects the position of tiny calcareous stones to determine which way is "up".

In plants

Plants could be said to exhibit a form of equilibrioception, in that when rotated from their normal attitude the stems grow in the direction that is upward (away from gravity) while their roots grow downward (in the direction of gravity) this phenomenon is known as Gravitropism and it has been shown that for instance Poplar stems can detect reorientation and inclination.