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https://www.youtube.com/watch?v=1AZnFszUroI&t=63s

D. Merfeld, in Encyclopedia of Neuroscience, 2009
The semicircular canals respond to head rotation but have a limited dynamic range; the otolith organs respond equivalently to both gravity (‘tilt’) and linear acceleration (‘translation’)....nervous system combines visual, vestibular, and other cues to yield estimates of tilt, translation, and rotation...combined information from the semicircular canals and otolith organs typically yields more accurate estimates of motion and orientation than would be attained via either sensory modality alone.

3 translational movements
3 rotational

The outer and middle ear are involved with hearing
The inner ear functions in both hearing and equilibrium
Receptors for hearing and balance:
Respond to separate stimuli
Are activated independently

Problems with the vestibular system can lead to peculiar sensations:
Spatial Disorientation: Any impairment of spatial orientation (i.e., our sense of linear motion, angular motion, or tilt)
Dizziness: Nonspecific spatial disorientation
Vertigo: A sensation of rotation or spinning
Imbalance
Blurred vision
Illusory self-motion

Vestibular organs: The set of five organs—three semicircular canals and two otolith organs

Where am I going?
Which way is up?
head motion
self position
spatial orientation in regards to gravity
Linear motion
Angular motion
Tilt
Allow for the vestibulo-ocular reflex VOR: Stabilizes visual input by counter rotating the eyes to compensate for head movement

Spatial orientation: A sense comprised of three interacting sensory modalities: Our senses of linear motion, angular motion, and tilt
1. Angular motion: Can be sensed when rotating head from side to side as if to say “no”
2. Linear motion: Sensed when accelerating or decelerating in a car
3. Tilt: Can be sensed when nodding head up and down as if to say “yes”
Why considered different “modalities”?
Sensing linear motion, angular motion, and tilt involves different receptors and/or different stimulation energy

Semicircular canals: The three toroidal tubes in the vestibular system that sense angular acceleration, a change in angular velocity
Source of our sense of angular motion
Otolith organs: The mechanical structures in the vestibular system that sense both linear acceleration and gravity
Source of our sense of linear velocity and gravity

Coordinate system for classifying direction:
x-axis: Points forward, in the direction the person is facing
y-axis: Points laterally, out of the person’s left ear
z-axis: Points vertically, out of the top of the head
Axes are defined relative to the person, not relative to gravity

Linear motion
Movements represented in terms of changes in the x-, y-, and z-axes
Any arbitrary linear motion can be represented as a change along these three axes

The vestibular organs do not respond to constant velocity
They only respond to changes in velocity—acceleration
Gravity and acceleration share a deep connection and can be considered equivalent

Semicircular canals
Each one is about three-fourths of a toroid (donut) shape, measuring 15 mm long and 1.5 mm in diameter
Canals are filled with a fluid called perilymph
A second, smaller toroid is found inside the larger toroid, measuring 0.3 mm in diameter
Formed by a membrane filled with fluid called endolymph
Cross section of each canal swells substantially near where the canals join the vestibule: Ampulla

Semicircular canals (cont’d)

When the head rotates, the inertia of the endolymph causes it to lag behind, leading to tiny deflections of the hair cells

Coding of direction in the semicircular canals
Three semicircular canals in each ear
Each canal is oriented in a different plane
Each canal is maximally sensitive to rotations perpendicular to the canal plane
is sensitive to changes in rotation velocity
Canal afferent neurons are sensitive to back and forth rotations of the head, as well

Otolith organs sense acceleration and tilt
Two otolith organs in each ear:
Utricle: Contains about 30,000 hair cells
Saccule: Contains about 16,000 hair cells
Each organ contains a macula: A specialized detector of linear acceleration and gravity
Each macula is roughly planar and sensitive primarily to shear forces
Hair cells are encased in a gelatinous structure that contains calcium carbonate crystals called otoconia (“ear stones” in Greek)

Utricular macula: horizontal plane
Sensitive to horizontal linear acceleration and gravity
Saccular macula: vertical plane
Sensitive to vertical linear acceleration and gravity

Sensory integration: The process of combining different sensory signals
Typically leads to more accurate information than can be obtained from individual senses alone

Visual–vestibular integration
Vection: An illusory sense of self motion produced when you are not, in fact, moving
Example: The feeling of flying while watching an IMAX movie
Example: Being stopped in your car at a light next to a semi. The semi begins to roll forward and you press on the brake because you feel as if you are rolling backwards

Thus, vestibular information is combined with visual information to yield a “consensus” about our sense of spatial orientation

Vestibulo-ocular reflexes (VORs): Counter-rotating the eyes to counteract head movements and maintain fixation on a target
Angular VOR: The most well-studied VOR
Example: When the head turns to the left, the eyeballs are rotated to the right to partially counteract this motion
Torsional eye movements: When the head is rolled about the x-axis, the eyeballs can be rotated a few degrees in the opposite direction to compensate
VORs are accomplished by six oculomotor muscles that rotate the eyeball

Vestibulo-autonomic responses
Autonomic nervous system: The part of the nervous system innervating glands, heart, digestive system, etc., and responsible for regulation of many involuntary actions
Motion sickness: Results when there is a disagreement between the motion and orientation signals provided by the semicircular canals, otolith organs, and vision
Could be an evolutionary response to being poisoned
Blood pressure is regulated by vestibulo-autonomic responses

We have a visual cortex and an auditory cortex; do we have a vestibular cortex? Not really
Areas of cortex respond to vestibular input, but they tend to respond to visual input as well
No need to have cortex for processing vestibular information in isolation if visual information is available also
Vestibular information reaches the cortex via thalamo-cortical pathways
Areas of cortex that receive projections from the vestibular system also project back to the vestibular nuclei
Knowledge and expectations can influence perception of tilt and motion

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The vestibular organs sense head motion: canals sense rotation; otoliths sense linear acceleration (including gravity).
The central vestibular system distributes this signal to oculomotor, head movement, and postural systems for gaze, head, and limb stabilization..
The visual system complements the vestibular system.
Visuo-vestibular conflict causes acute discomfort.
Peripheral and brainstem vestibular dysfunction causes pathological sense of self-motion and visuo-vestibular conflict.

Vestibulo-ocular reflex – keep the eyes still in space when the head moves.
Vestibulo-colic reflex – keeps the head still in space – or on a level plane when you walk.
erin harding Today, 3:21 PM
Vestibular-spinal reflex – adjusts posture for rapid changes in position.

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