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COURSE: PHS212; HUMAN PHYSIOLOGY II

ASSIGNMENT

THE PHYSIOLOGY OF BALANCE

The sense of balance originates in the labyrinth, the bony labyrinth is a convoluted system of tunnels in the skull that contains the sensors for hearing and balance. The inside of these tunnels is lined with a membrane, the space between the bone and the membrane contains perilymph a fluid somewhat similar to extracellular fluid. Endolymph, a fluid similar to intracellular fluid (i.e. high K+, low Na+) fills the inside of the membrane and surrounds the balance receptors. Endolymph bathes the hair cells in both the auditory and vestibular system. Endolymph has a +80 mv charge with respect to the perilymph. The sensors for hearing are close to those for balance because they have a common origin. The common origin is the lateral line organ that first evolved in early fish. This organ consists of tubes that lie along the fish's side. As the fish swims, water flows through these tubes and across the sensory cells, which have hair-like projections that are bent by the water. Fluid movement in the tubes is caused by

1. Waves produced by some noise in the water (the precursor of the auditory system) and

2. The fish's own motion (the precursor of balance or the vestibular system).

The vestibular system has two parts, the otolith organs and the semicircular canals.

Each has a different function.

The Otolith Organ senses the heads' increasing speed in a straight line. They can be either forward or backward, left or right, up or down. Or any combination of these. They are also able to sense the head's position relative to gravity. These are the organs that tell us whether we are upside down or right side up. While the semicircular canals detect the head's rotation (turning/angular motion)

The Anatomy of the Otolith Organs; inside the otolith organs are two sacs called the utricle and the saccle. On the inside of each a portion of the sac is thickened and called the macula. The macula contains hair cells innervated by neurons of the 8th nerve. The hair cells project into a gel. Calcium carbonate crystals (ear stones) are embedded in this gel. The purpose of the stones is to give the gel extra mass. This mass helps bend the hairs when subjected to motion or gravity. The thickest and longest of the hairs is the kinocilium.

Motion is transduced into neural firing when it bends the hairs in auditory hair cells, Endolymph, high in K+ and low in Na+ surrounds the hairs, when the filament between adjacent hair opens ion channels. The endolymph's positive voltage pushes K+ into the negatively charged hair cell, when the hair cell depolarizes, releasing neurotransmitter and when there is an increase in the frequency of AP's in the 8th nerve afferent.

Bending of the Hairs; when the hairs are undisturbed, the vestibular afferents have a resting firing rate of about 100 action potentials per second. When the head moves, the inertia of the crystals bends the hair cells in the opposite direction. Bending all the hairs towards the tallest hair, the kinocilium, opens the ion channel and depolarizes the cell, inducing an increase in action potential frequency in the 8th nerve afferents. Bending away from the kinocilium closes the ion channel and causes hyperpolarization and reduces the action potential frequency.

In addition to head movements, gravity "pulls" on the stone crystals. When head position changes, the direction of this gravitational "pull" changes, telling you that your head is tilted. Within the macula of the utricle and saccule, the kinocilium of the hair cells are oriented in all possible directions on the surface of the macula (the location of kinocilium is indicated by the red arrows). The direction of linear acceleration or gravity is determined by which hair cells are most bent toward the kinocilium. With the head upright, the macula of the utricle (green) is in the horizontal plane and senses left/right and forward/backward translations. The macula of the saccule (blue) is on the side and senses translations in the vertical plane (up/down and forward/backward)

The semicircular canals sense head rotation.

There are three canals on each side of your head. One is approximately horizontal (h), and the other two, the anterior (a) and posterior (p), are vertical. All three are about perpendicular to each other and thus form three sides of a cube. Within the canals are endolymph-filled semicircular ducts and each has a swelling called the ampulla. A pliable membrane called the cupula seals the inner diameter of the ampulla. The hairs of the hair cells project into the cupula.

The canals detect angular acceleration of the head when there is a change in speed of head rotation, the endolymph fluid lags behind, because of inertia, pushing on and distorting the cupula. The bending of the hair cell hairs causes increase or decrease of the hair cell potential, depending on whether bending occurs towards or away from the kinocilium.

The canals compute direction of head rotation since there are three canals on each side of the head and they are roughly perpendicular to each other, the activity in the canals decomposes all rotation into three components, so much to the right, so much downward, and so much clockwise. Also, the canals are arranged such that each canal has a partner on the other side of the head. When one partner’s hair cell potential is increased, the other’s is decreased. This is called a push-pull organization. When the rotation is in the plane of a canal push-pull pair, the potential of this pair’s cells are increased or decreased while the other four canals show no change. When the head rotates rightward in the plane of the horizontal canals, the potential increases in the horizontal canal on the right side of the head and decreases in the left. No change in potential occurs in the other four canals.

The anterior canal on one side and the posterior on the other also form push-pull pairs. When you tip your head forward and to the left ear, in the plane of the left anterior canal, this canal’s hair cells increase in potential while those of the right posterior canal decrease. No other canal changes its activity. When you tip your head forward and to the right ear, the right anterior canal’s hair cell potential increases while those of the left posterior decreases.

The Vestibular Ocular Reflex (VOR)

The otoliths and canals activate many postural reflexes. These connect to muscles in your legs, trunk and arms and keep you upright. Another key reflex is one that turns the eyes, the vestibular ocular reflex (VOR). The important function of the VOR is to stabilize the retinal image during rotations of the head.

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To maintain a clear image, requires keeping the eye still in space in spite of any head translation or rotation. For example, when the head rotates with a certain speed and direction, the eyes must rotate with the same speed but in the opposite direction .The ratio of the eye and head rotations is called the gain of the VOR. The ideal gain is -1. This gain keeps the image of the world stationary on the retina. Many of the newer smartphones use Optical Image Stabilization for the same reason.

The neural mechanism for a horizontal VOR.

1. When the head rotates rightward, the following occurs:
2. The right horizontal canal hair cells depolarize (potential increases) while those of the left hyperpolarize (potential decrease).
3. The right vestibular afferent activity increases, while activity of the left decreases.
4. The right vestibular nucleus' activity increases while that in the left decreases.
5. In the cranial nerve (motoneurons to extra ocular muscles), neurons in the left 6th and right 3rd nerve nuclei fire at a higher frequency.
6. Those in the left 3rd and right 6th nerve nuclei fire at a lower frequency.
7. The left lateral rectus (lr) extraocular muscle and the right medial (mr) rectus contract.
8. The left medial rectus and the right lateral rectus relax.
9. Both eyes rotate leftward.

The VOR gain is determined by the difference between the direct and indirect paths. The cerebellum's task is to keep this difference optimal in spite of all the changes that may occur to the various parts of the direct VOR

When VOR is not working properly (e.g. the eye is not rotating enough or too much) a slip of the image is detected by the retina and sent to the cerebellum via the inferior olive climbing fiber input. This teacher's input semi-permanently alters the synapses of the students; those synapses activated by both the parallel fibers and the Purkinje cell dendrites. This increases or decreases the cerebellar inhibition of the vestibular nucleus. When the activity of the vestibular nucleus is just correct, the retinal slip stops and the teacher is silenced. The cerebellum acts like a repair shop. It makes similar re-adjustments to all our reflexes.

Alcohol and many drugs affect the function of the brain and this repair shop. It is thus not surprising that when the repair shop malfunctions, the VOR becomes uncelebrated, and one feels dizzy

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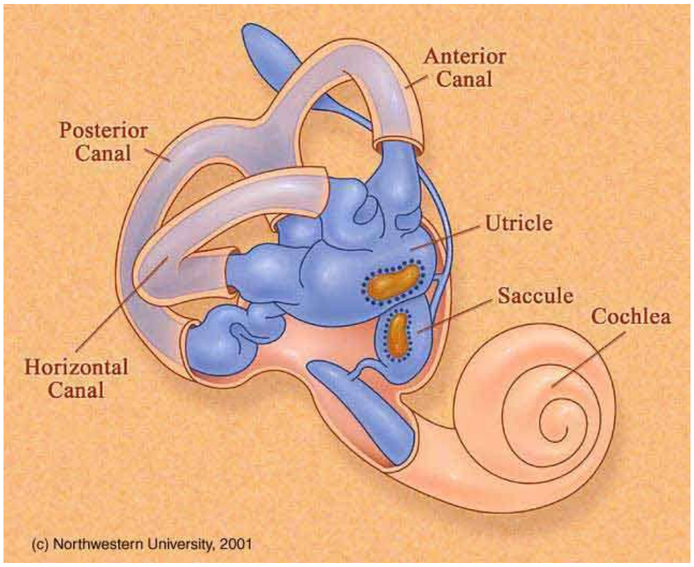
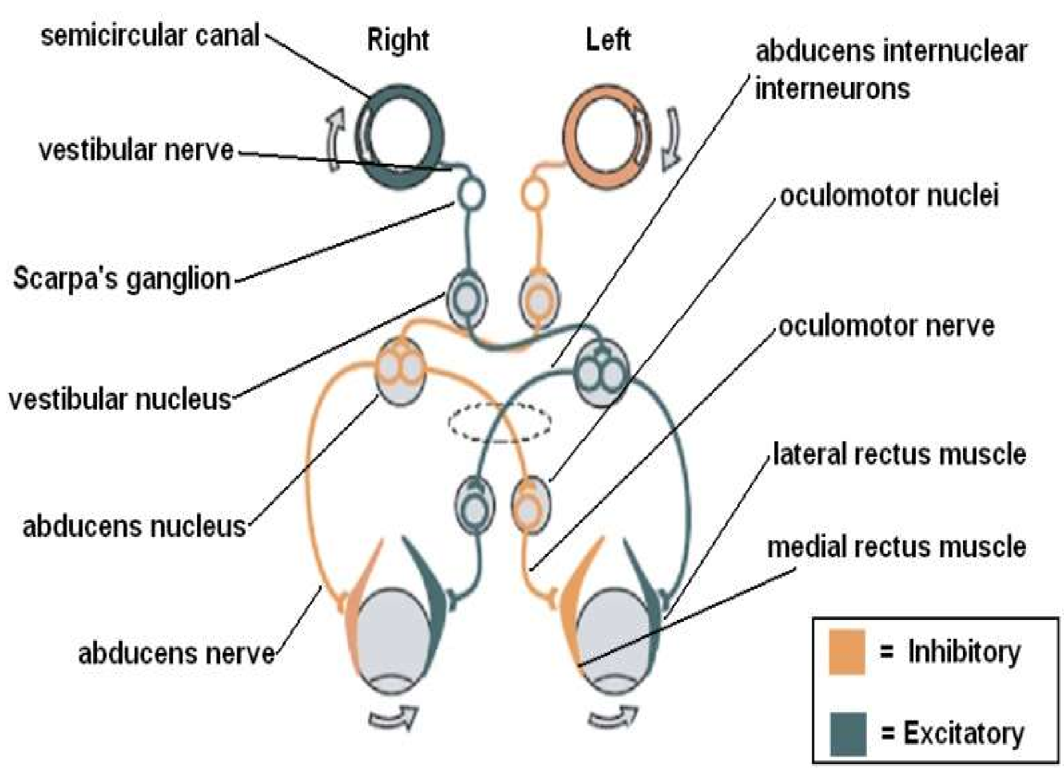
Images;





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https://www.google.com/search?q=vestibulo+ocular+reflex&sxsrf=ALeKk03tqy3ALH6SsRNG_BOZk3ttHM_oGQ:1591809853162&source=lnms&tbm=isch&sa=X&ved=2ahUKEwirtOPm4ffpAhUIkhQKHaMuDZ4Q_AUoAXoECBYQAw&biw=1536&bih=754#imgrc=yctZ8BIHVszV8M

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