

Lecture Review for Audition and the Vestibular System

As I mentioned on previously, these reviews are intended to help you focus your study time. They are not meant in any way to be a comprehensive summary of everything you will be expected to know for the exam. You should focus your study time on the lecture notes and read the book and provide reading on the vestibular system.

The inner ear contains the sensory structures for two sensory systems, **audition** or hearing, and the **vestibular system** or the sense of balance.

Vibrating objects create pressure waves in which air molecules vibrate back and forth. These pressure waves, or sound waves, are detected by the auditory system when they impinge on the tympanic membrane of the ear. Certain features of sound waves are used by the auditory system to characterize the sound. These features include the **frequency** of the waves, the **loudness** of the sound, and the **location** of the sound wave source. I discussed each of these characteristics in lecture in detail. You should know how each of these characteristics is coded by the nervous system.

The anatomy of the ear was reviewed (see Fig. 11.3 for the basic structures). You will be expected to know the three divisions of the ear (the **outer**, **middle**, and **inner ear**) and the components of each division. I talked about the bones of the middle ear (**auditory ossicles**) that convey the vibrations of the tympanic membrane to the oval window, but don't worry about memorizing the names of the individual bones. The inner ear is embedded in the temporal bone and it consists of fluid filled chambers called the **membranous labyrinth**. The membranous labyrinth is composed of a **superior portion**, which contains the end organs of the vestibular system, and an **inferior portion**, which consists of the **cochlea**. The cochlea is a spiral-shaped organ that spirals around a central structure called the **modiolus**. The cochlea is divided into three chambers the **scala vestibuli**, **scala media**, and the **scala tympani**. Each of these chambers run the length of the cochlea, and is separated from one another by a membrane. The most important membrane is the **basilar membrane**, which separates the scala media from the scala tympani. The receptor epithelium of the cochlea is situated on the basilar membrane. Each chamber is filled with fluid. The scala tympani and vestibuli are filled with **perilymph**, which is high in Na^+ and low in K^+ . The scala media is filled with **endolymph**, which is high in K^+ and low in Na^+ . An easy way to remember which chamber contains which fluid is that the scala tympani and vestibuli lie around (peri = around) the scala media. In the cochlea, the sound wave vibrations are converted into electrical signal. When sound waves cause the tympanic membrane to vibrate, the motion of the stapes on the oval window create fluid pressure waves that are transmitted down the scala vestibuli. These pressure waves are transmitted from the fluid of the scala vestibuli to the fluid in the scala media. Because the basilar membrane is flexible it is deformed by the pressure waves in the scala media. As discussed in class, the mechanical properties of the membrane and the frequency of the sound wave determine exactly where the maximum deformation of the basilar membrane occurs. The base of the basilar membrane is stiffer and narrower than the apex, and so it is maximally deformed by higher frequency sounds. As you progress towards the apex the basilar membrane becomes more flexible and wider. As you progress towards the apex maximal deformation occurs at lower and lower sound wave frequencies. Thus, there is a

frequency map (**tonotopy**) along the basilar membrane. This tonotopy is relayed from neural center to neural center in the auditory pathway.

The receptors of the cochlea are contained in a structure called the **organ of Corti**. The receptors are called **hair cells**. The hair cells have 100 or more stereocilia extending from their apical surface and are contacted at their basal end by the sensory afferents of the eighth nerve (vestibulocochlear nerve). The cochlear hair cells extend their stereocilia into the **tectorial membrane** that overlies the organ of Corti. Movements of the basilar membrane relative to the tectorial membrane (as occurs when the basilar membrane is deformed by pressure waves) acts to move the stereocilia and activate the hair cells. The hair cells are divided into two groups: the **inner hair cells**, and the **outer hair cells**. The inner hair cells are fewer in number, but receive most of the sensory afferents and are the main auditory transducers. The outer hair cells are more numerous, receive a minority of the sensory afferents. The outer hair cells appear to act as a **cochlear amplifier**. The outer hair cells have the ability to resonate their length with the stimulus frequency, which acts to amplify the deformation of the basilar membrane and enhance the response of the inner hair cells. The stereocilia of the hair cells are mechanically linked to one another and to K^+ channels. You should understand how hair cells transduce the mechanical movement of the endolymph.

The hair cells of the cochlea are innervated by neurons that have their cell bodies in a ganglion called the **spiral** or **cochlear ganglion**. The central auditory pathways in the brain involve nuclei at the level of the medulla, midbrain, thalamus, and isocortex. You should know the pathway and nuclei as summarized in figure 11.18. With regard to function of the nuclei of the auditory pathway, you should know that the **dorsal cochlear nucleus** is involved pattern recognition (music, words, etc.), whereas the **ventral cochlear nucleus** is involved the pathway that compares inputs from both ears in order to localize the sound source. The ventral cochlear nucleus projects bilaterally to the **superior olive**. The superior olive consists of two divisions, a medial and lateral division, which are responsible for detecting interaural time and intensity differences, respectively. This information is relayed to the **inferior colliculus**, which integrates it to create a map of auditory space surrounding a person. Auditory information is relayed to the **auditory cortex (area 41)** through the **medial geniculate** of the thalamus.

The **semicircular canals** and **otolith organs** of the membranous labyrinth mediate vestibular functions. As I discussed in lecture, each of these sets of organs sense different aspects of head movement. The otolith organs sense changes in head position relative to gravity (they are sometimes called gravistatic organs) and linear accelerations and decelerations of the head (when you ride in a car). The otolith organs initiate postural reflexes designed to accommodate the load shift of your head and keep you standing or sitting upright. The semicircular canals sense angular accelerations of the head (shaking your head "yes" or "no"). The hair cells of the otolith and semicircular canals are innervated by neurons that have their cell bodies in a ganglion called **Scarpa's ganglion**. The sensory afferent from Scarpa's ganglion synapse on neurons in the vestibular nuclear complex in the medulla. The four nuclei of the vestibular nuclear complex make three sets of connections in the brain. You should know these four sets of connections as summarized in lecture.