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Part 1 of this four-part series described how sound is transmitted from its source through the outer and middle sections of the ear. This article follows the auditory pathway through the inner ear to the brain, where sounds are interpreted.

**THE INNER EAR**

The inner ear consists of several fluid-filled chambers encased in a bony labyrinth or maze in the temporal bone of the skull and behind the eye socket – this is a safe position for a number of delicate receptors. The semicircular canals found here are vital for balance and will be discussed in part 3. The auditory apparatus in the inner ear is the cochlea, a tube coiled like a snail’s shell with closed ends (Fig 1). At the centre of the cochlea is a bony core called the modiolus.

The tube of the cochlea is divided along its length into three ducts or canals (Fig 2). Two of these (the vestibular and tympanic ducts) contain fluid of the same composition (perilymph) and are separated by the basilar membrane. These ducts are interconnected at the top of the apex of the cochlea. The third chamber, the medial or cochlear duct, is filled with a different fluid (endolymph) and also contains the auditory receptor cells of the organ of Corti.

When the oval window of the middle ear vibrates with the plunging action of the staples (see part 1), the fluid in the vestibular duct is set moving in a similar back-and-forth motion and the vibration is transmitted to the basilar membrane. During these movements, the basilar membrane moves up and down and a pressure wave travels through the perilymph. The pressure wave sets the entire basilar membrane into vibrations. The louder the sound, the greater the movement of the basilar membrane. Maximal displacement of the membrane occurs where the fibres of the basilar membrane are ‘tuned’ to a particular sound frequency – those nearest to the oval window respond to high-frequency pressure waves and those near the cochlear apex to sounds of lower frequency (Marieb, 2006).

**AUDITORY RECEPTOR CELLS**

The organ of Corti, which rests on top of the basilar membrane, contains about 16,000 hearing receptor cells – hair cells, so called because of their bristle-like projections (Fig 3). Sensory (afferent) fibres of the cochlear nerve (a division of the 8th cranial nerve – the vestibulocochlear or auditory nerve) are coiled around the bases of the hair cells.

The hair cells bend when the basilar membrane vibrates in response to sound, which opens channels allowing potassium and calcium into the cells, depolarising them. This, in turn, sets off an electrical stimulus in the hair cells and sensitises the fibres of the cochlear nerve. In this way mechanical energy from sound waves is turned into electrical energy in the inner ear.

The number of hair cells responding in a given area of the organ of Corti provides information to the brain on the intensity of the sound (Allan, 2005).

**NERVE PATHWAYS TO THE BRAIN**

The axons of the sensory or afferent fibres of the cochlear nerve enter the medulla oblongata and synapse with other neurons at the cochlear nucleus (Martini, 2005). Some fibres from each ear cross the central line of the brain and so each cortex receives impulses from both ears (Marieb, 2006). The information ascends to the processing centre in the mesencephalon, which coordinates a number of responses to acoustic stimuli. These include auditory reflexes that activate muscles in the head,
face and neck, changing the position of the head in response to sudden loud noises – the head and eyes usually turn towards the source of the sound (Martini, 2005).

Information also passes to the auditory cortex in the temporal lobe of the brain. High-frequency sounds activate one area of the cortex and low-frequency sounds another. In effect the auditory cortex retains a map of the organ of Corti (Allan, 2005). In the cerebral cortex, information about the sound’s frequency is interpreted to produce subjective sensations of pitch.

**INTERPRETATION OF SOUND**
The auditory cortex is able to analyse sounds to such a high degree that it can pick out the sound of a single instrument from a whole orchestra or a single voice in a noisy room. Pitch, loudness and sound location are all processed in different areas of the cerebral cortex.

If the auditory cortex is damaged the individual will respond to sounds and have normal acoustic reflexes but interpretation and pattern recognition will be difficult or impossible (Martini, 2005). The left hemisphere contains an area known as Wernicke’s area, which is concerned with analysing speech. If this is damaged, the patient can hear sounds but is unable to interpret them (sensory, or receptive, aphasia). Damage to the corresponding area in the right hemisphere will leave the understanding of language intact but will cause problems with recall, recognition and discrimination of non-verbal sounds (Allan, 2005).

**HEARING LOSS**
Hearing loss in the outer and middle ear is usually due to a conduction problem but in the inner ear and brain the problem generally lies with the structures from the cochlear hair to the auditory cortex cells. This is known as sensorineural deafness and could indicate neurological disease.

Sensorineural deafness may be partial or complete and often results from the gradual loss of the hearing receptor cells throughout life. These cells can also be destroyed by a single explosively loud noise or prolonged exposure to high-intensity sounds, which cause them to stiffen or tear. Degeneration of the cochlear nerve, cerebral infarcts and tumours in the auditory cortex are other causes (Marieb, 2006).

Bacteria from inner ear infection or drugs, such as aminoglycoside antibiotics (neomycin or gentamycin), may also diffuse into the endolymph and kill the hair cells. Little can be done for sensorineural deafness, although for age or noise-related cochlear damage, cochlear implants can be inserted into the temporal bone. These do not provide normal hearing but do enable the user to sense sound (Marieb, 2006).

People with impaired hearing can receive advice from the Royal National Institute for the Deaf (www.rnid.org.uk).

**REFERENCES**

