NEUR30003 Lecture 9 (Auditory System)

In auditory systems, it's the vibrations in the air around us that we detect
-Vibrations like relative compressions and rarifications or expansions of the air (soundwaves)
Hair cells 2types: Inner and outer
-Inner hair cells do the transduction
Receptive Field: peak of travelling in the inner ear

Key concepts in sensory system description:
-Transduction (how is energy captured and transformed)
-Receptive field (what stimuli can change neuronal activity)
-Sensitivity and range
-Resolution (spatial and tempo)

energy	receptor	range	Sensitivity & dynamic range	Receptive Field
EM radiation	Rod & cone photoreceptors	400 to 600 nm wavelength	Single photon to bright sunlight (10^{10} fold)	Single photoreceptor, concentric ganglion cell
Distortion of skin	Various encapsulated nerve endings	10nm to sub-damaging distortion	mg, 0-1000 Hz	Ovaloid from $10mm^2$ to entire hand
Vibration in air	Inner hair cell	20 - 20,000Hz	picometers to 100dB	Peak of travelling wave?

Sound is the relative changes in air pressure caused by vibrating objects
Vibrations are being detected for sound to be produced
Percepts related to sound energy parameters
→Wavelength (pitch)
→Amplitude (volume, loudness)
→Waveform (tone/timbre)

Outer ear: does provide information about sound
→Sound waves are attenuated slightly by the outer ear depending on where they come from
Inner ear: snail-like cochlea
→This is where transduction happens
Middle ear: Tympanic membrane
-Made of connective tissue and vibrates with the air pressures that come in
→Air vibrations are transferred into this
→This movement is transferred into different levers (moves to movement of little bones)
→This pushes the last of the levers (Stapes) onto the spiral organ (cochlea)

-External ear amplifies around 3,000Hz
→Some elevation enhancement of high frequency
→Good at filtering stuff not at 3000Hz cause that is the sound most speeches are in

The cochlea is full of fluid and we have to get those mechanical waves transferred into that fluid
The air that moves the tympanic membrane is a gas
→When you're trying to get movements of one medium to another, it's hard
→Sound wave bounces off the surface of the water so the swimmer doesn't hear much of what you say from the surface

Tympanic membrane converts large vibrations on it of relatively little force, so you get high force with small amplitude at the base of stapes in oval window, which is a force multiplier

Transduction: the cochlea
Triple chamber (Scala vestibule, Scala media and the Scala tympani)
-When the stapes bones vibrate, it sets up a vibration that travels through the scala media and the scala tympani
→So the whole system is vibrating

In the middle, the scala media, is where mechanical transduction of the vibrations in the fluid is converted to nerve impulse
-On the base of the scala media is a membrane, the Basilar membrane, made of connective tissue and collagen fibres
-On top of that membrane, is the organ of corti (collection of cells)
-Inner hair cells→Produce neural activity in response to the vibrating fluid
→Inner hair cells have protrusions, Sterocilia

Basilar membrane vibrates when the fluid vibrates (it's going to move up and down
There is another membrane sitting on top of the organ of corti, Tectorial membrane
The tips of the sterocilia hair cells are embedded onto that membrane

When sterocilia of outer hair cells are activated, they can stiffen the Basilar membrane

Travelling waves along the cochlea
-Get a travelling wave of vibration
-Vibration of the structure is not the same all along
→Construction of the basilar membrane is different
-Closer to the base, the fibres are thicker and the membrane is compact and thick
-Closer to the cochlear apex, the basilar membrane is wide and floppy
-Basilar membrane is thin→Kind of movement here depends on the frequency
-High pitch sound, vibrate where it's short and compact
-Low pitch sound, vibrate down where it's long and floppy

→This is called Spectral decomposition

The spectrum of sound from 20Hz to 20kHz will activate different regions

Those 2 membranes on either sides of the inner hair cells have different fulcrums/pivot points
The inner hair cells are wiggled back and forth as the basilar membrane pushes up and tectorial membrane slides up and down against the hair cells

Mechanoelectrical transduction mediated
-Tipplings mechanically gate ion channels
-They open K+ channels and let K+ in if the tiplings are moving and depolarizes the cell
-Depolarisation causes voltage gated Ca2+ channels to open and signal is transmitted

Stria vascularis is a blood vessel in the ear
-They are full of Na+/K+ exchange pumps and pump K+ out against it concentration gradient

Where the signal goes?
-We can recognize pitch with labeled lines
→If middle of the basilar membrane is most active, neurons there are active and the signal goes to the brain. The fact that it is from that location tells us that it is a medial frequency
-K+ comes on as the hair cells wiggle back and forth
-We recognise pitch with labelled lines
-The fact that it is from that location of the membrane will tell is the pitch

-As the membrane goes up and down, it activates the cell at that frequency
-At a 1000Hz, bit of the membrane that is active is activating cell at a 1000Hz
→Neurons is firing at 1000Hz and the nerve impulse going to the brain is also a 1000Hz
-THIS IS ONLY GOOD FOR THE RANGE OF FREQUENCIES NEURONS CAN FIRE AT (1000hz/s)-
-When you get 2000 cycles/sec, no neuron can fire at 2000Hz/s
-Information about pitch at 1-2k/Hz doesn't come from the frequency of the nerves firing, it comes from the basilar membrane that is most activated by the frequencies
→If you are hearing 3kHz sounds, nerves from the basilar membrane are max-ed out and firing at probs 100Hz/s, but you hear it as a 3kHz pitch cause your brain knows where it is coming from

The tuning is a broad activation of cells (1kHz doesn't mean hear at exactly 1kHz, but around that range)

-The auditory system crosses over at multiple levels
-When sound comes into the brain stem, it is shared at both sides of the brain at multiple points

Superior olive
→Structure allows us to find the origin of the sound
-Does so by calculating the time the sound comes from one ear to the other ear
-All the signals come to an array of nucleus

> →Cell A from right max activated and took a long path to the superior olive but cell B from left took a short path
>
> -For a cell to be maximally activated, it means the sound was much closer to that ear even though it had a longer projection cause it still reached at the same destination as the shorter pathway cell at the same time

-There's an acoustic shadow if your head is big (bigger than birds and all that)
-Input from one ear and input from the other ear do not cross over. As soon as you have an advantage on one side, it also inhibits the other side (if it's louder on one side, don't want to hear on the other side)

Cortical representation of auditory information
-Primary auditory cortex
→Tonotopic mapping of frequency
→Basilar membrane is mapped out in the cortex

1. Sound waves of varying pressure propagate through the air to reach the ear, reaching the outer ear propagates down the auditory canal producing vibrations in the tympanic membrane. Three middle ear bones or ossicles, the malleus, incus and stapes, transfer vibrations efficiently from the tympanic membrane (air) to the oval window (liquid) by amplifying pressure. The Eustation tube allows equalisation of pressure across the tympanic membrane.

2. Within the inner ear the coiled cochlea contains two liquid filled chambers, the scala vestibuli and scala tympani (low potassiumion concentration), separated by the cochlear duct (scala media – high potassium ion concentration) containing the basilar membrane. The Organ of Corti sits on top of the basilar membrane with many mechanically supporting cells. A single row of inner hair cells and three rows of outer hair cells are anchored to the basilar membrane with cilia of the outer hair cells contacting the tectorial membrane.

3. The basilar membrane is narrower and stiffer at the base and becomes wider and more elastic towards the apex so that high frequency sounds cause maximum vibration at the base end and low frequency sounds cause maximum vibration at the apical end. Thus hair cells and their innervating fibres have a corresponding tonotopic organisation (map of frequency space).

4. Transduction occurs at the organ of Corti. Vibration of the ossicles leads to the oval window and round window vibrating in and out and causes the Organ of Corti to vibrate up and down. The basilar membrane and tectorial membrane have different 'pivot points' so that there is relative tangential motion between them, and therefore the cilia are bent forwards and backwards. When the stereocilia bend towards the kinocilium, the resulting tension in the "tip links" opens potassium ion channels causing depolarization or excitation and vice-versa.

5. The apical surface of the hair cells is exposed to a high potassium ion concentration, the basal surface to a low concentration, this allows potassium to flow into the cells at the apex when potassium channels are mechanically opened (which depolarises the cell), and out of the cells in the basal region due to the concentration gradient.

6. The auditory pathway is essentially bilateral beyond the cochlear nucleus. Tonotopy is preserved in the central auditory nuclei and the auditory cortex. Sounds reaching the two ears from a distant source differ in time of arrival and in intensity. These differences increase as the

sound source moves further from the midline and allow the sound source to be localised in space.