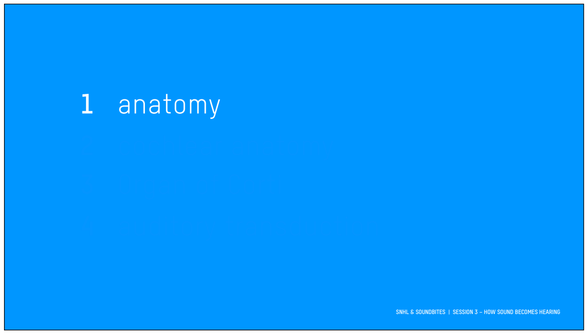
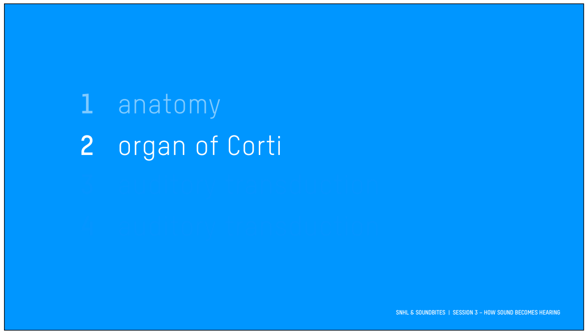
1

Hi, and welcome to Session 3, How Sound Becomes Hearing. This session covers normal auditory transduction.



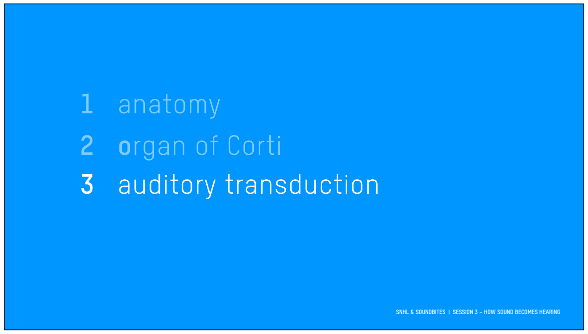
2

First, I'll briefly summarize ear anatomy



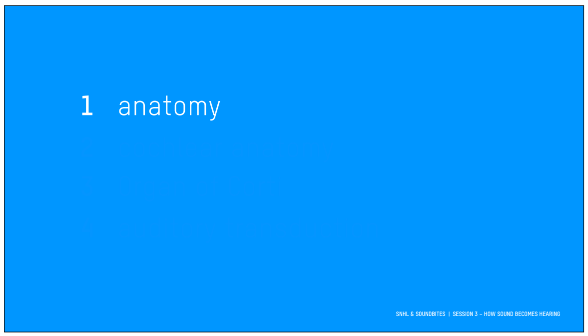
3

Then I'll cover the anatomy and physiology of the the organ of Corti within the cochlea.



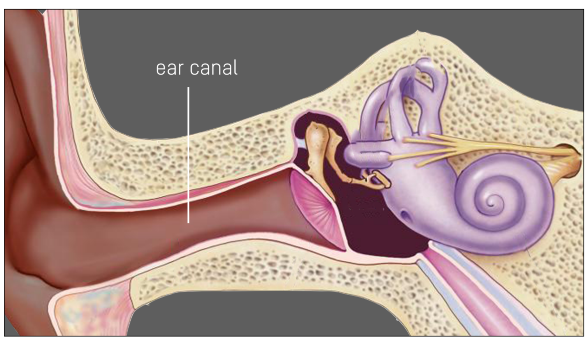
4

Finally, I'll cover auditory transduction, the process of making sound waves into hearing by converting vibrational energy into electrical energy.



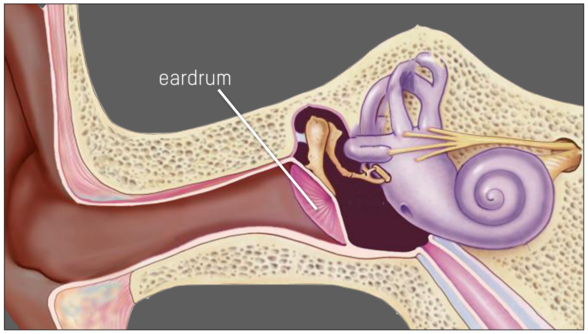
5

I'll start by reviewing ear anatomy.



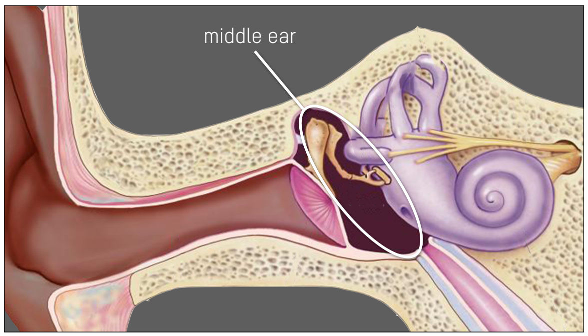
6

Sound waves enter through the ear canal, where we put earplugs, earbuds and hearing aids.



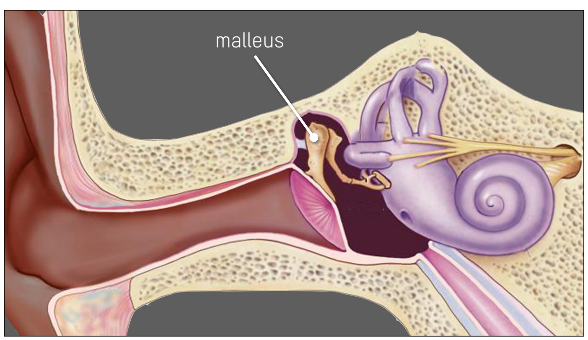
7

Sound waves cause the flexible tympanic membrane, commonly called the eardrum, to vibrate.



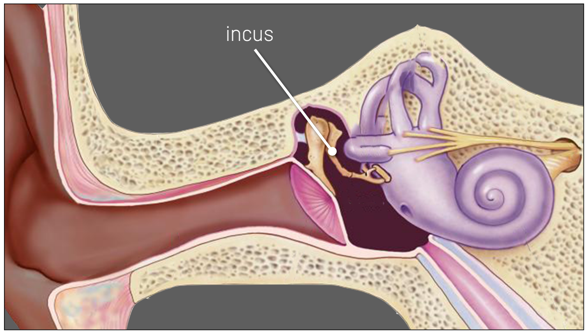
8

The eardrum seals the middle ear from the outer ear. The middle ear is filled with air.



9

Three of the smallest, hardest bones in the human body are in the middle ear. These bones, called ossicles, transfer the sound waves from the middle ear into the inner ear. The malleus, the hammer, is attached to the eardrum.



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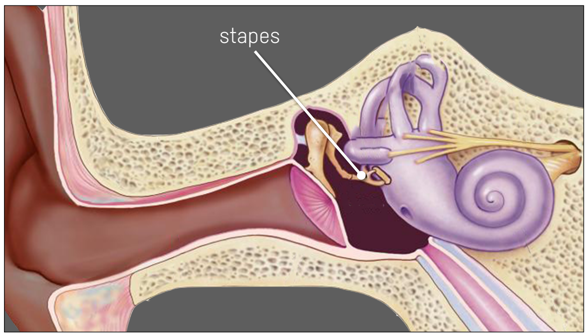
The malleus moves the incus, the anvil.



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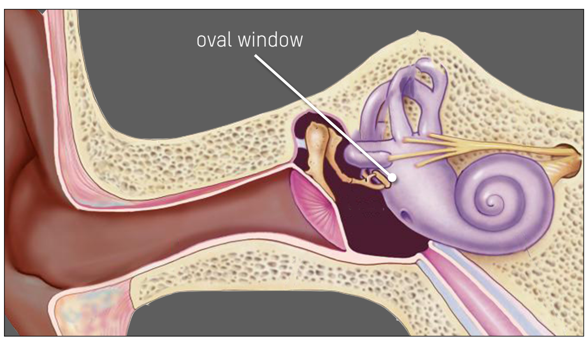
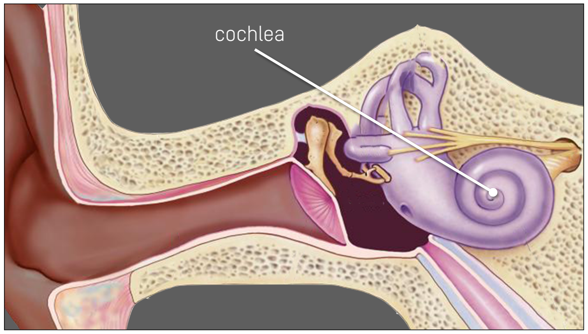
which moves the stapes, the stirrup.

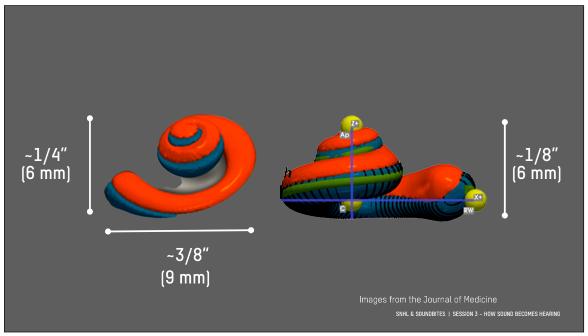


12

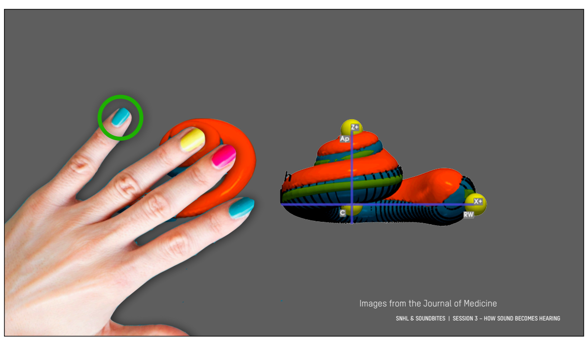
The stapes pulsates another flexible membrane called the oval window that separates the middle ear from the inner ear.



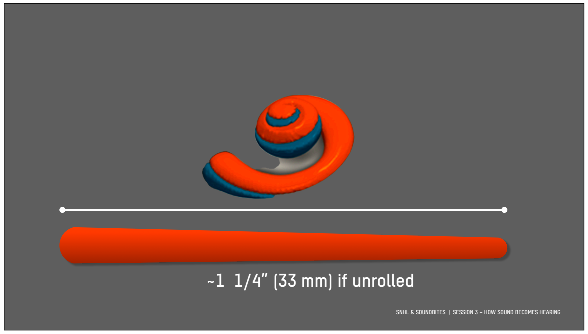
13 Oval window pulsations transfer sound waves into the upper canal of the fluid-filled inner ear, the cochlea.



14 This is a computer-generated image of the cochlea, a tiny spiral cavity about a quarter inch wide, three-eighths-of-an-inch long, and about one eighth-of-an-inch high.

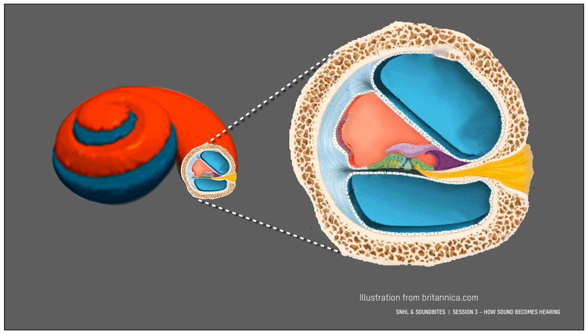


15 The cochlea is smaller than the fingernail on your little finger. The organ of Corti is even smaller, inside the cochlea.



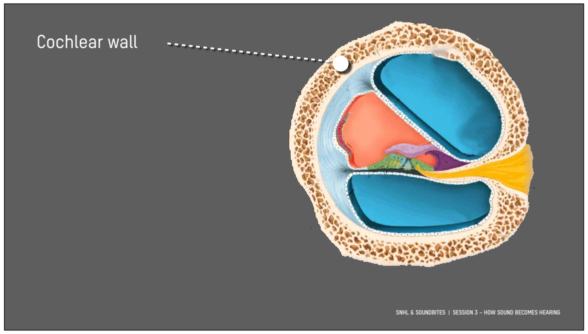
16

If you could unroll it, the cochlea would be about 1 and a quarter inches long.



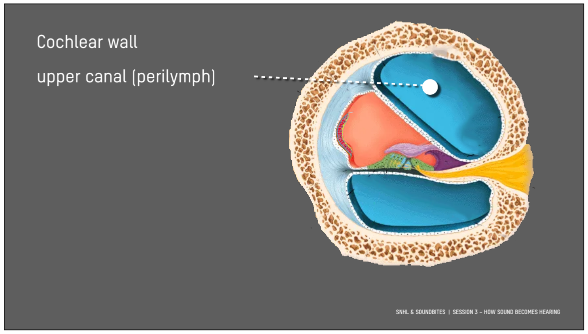
17

This is a cross section illustration of the inside of the cochlea. We're looking into the spiral-shaped tunnel.



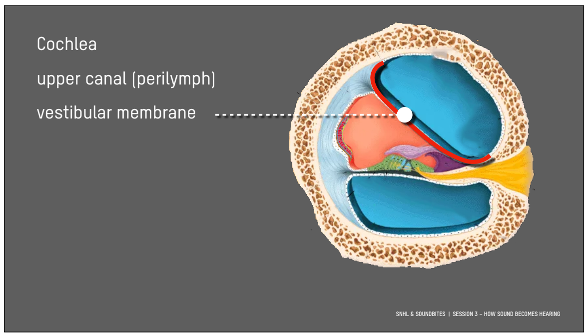
18

We see the outer wall of the cochlea…



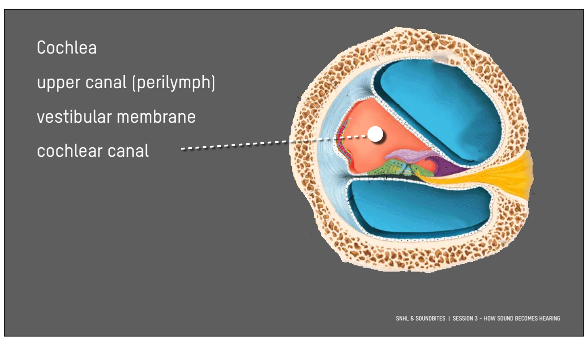
19

and the upper canal, where sound waves enter through oval window pulsations. The upper canal is filled with fluid called perilymph, similar to the fluid that flows in and around the brain and spine.



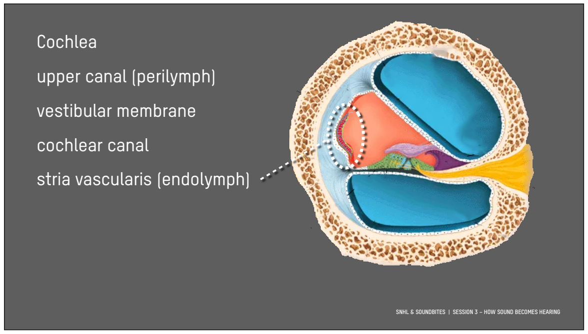
20

Pulsations move the flexible vestibular membrane, which transfers the sound waves…



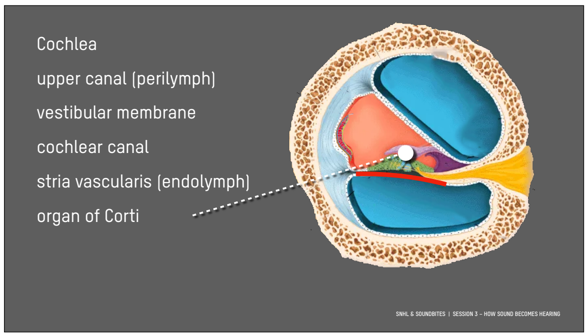
21

into the cochlear canal.



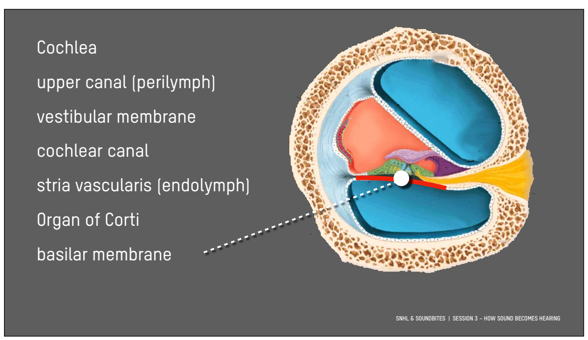
22

The stria vascularis in the cochlear canal contains a network of capillaries that circulate blood, secrete endolymph fluid into the cochlear canal and deliver nutrients to inner ear cells. **Endolymph fluid is found nowhere else in the body.** This is important for auditory transduction.



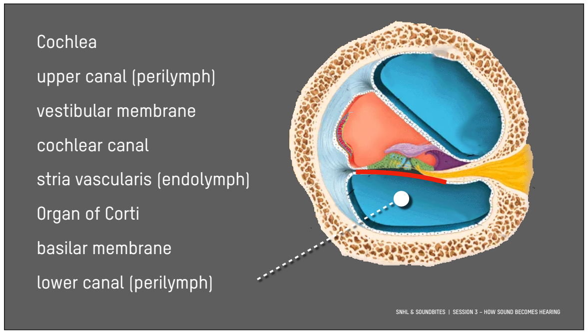
23

The Organ of Corti is located in the cochlear canal.



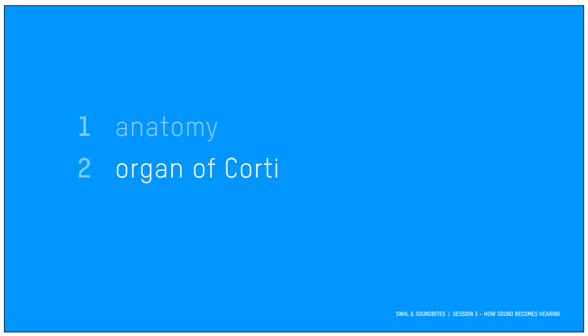
24

The organ of Corti rests on the basilar membrane.



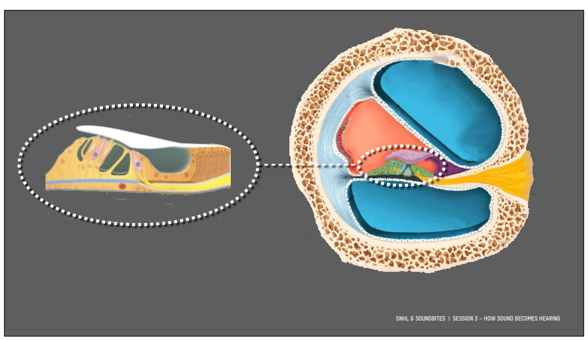
25

The basilar membrane separates the cochlear canal from the lower canal, which is also filled with perilymph. The basilar membrane moves in response to perilymph fluid movement in the upper and lower canals.



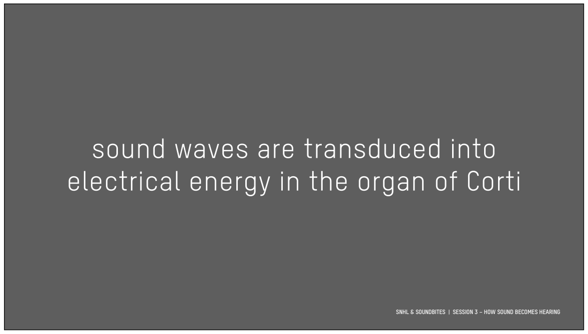
26

Now let's look at the physiology in the organ of Corti that drives auditory transduction.



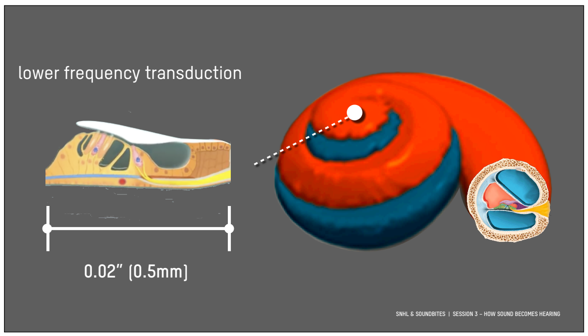
27

The illustration on the left magnifies the cross-section of the organ of Corti. The organ of Corti is named for the Italian biologist Alfonso Corti, who discovered it in 1851 at the age of 29.



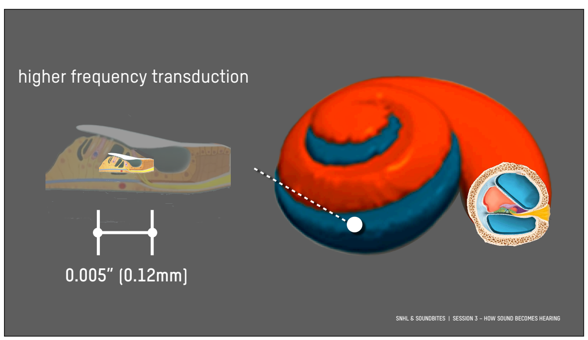
28

Transduction is the biological process of converting one type of energy into another. Sound waves are transduced into electrical energy in the organ of Corti.



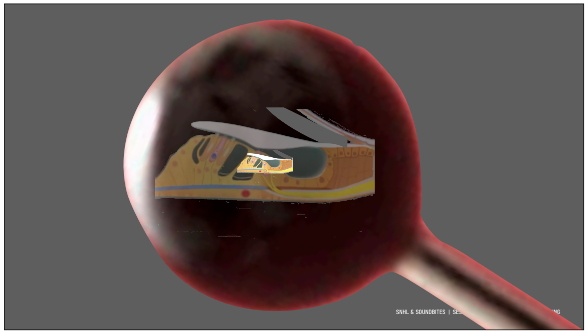
29

The organ of Corti gets narrower as it winds through the cochlear spiral. It's about 2 hundredths of an inch across at the top, where low frequencies are transduced.



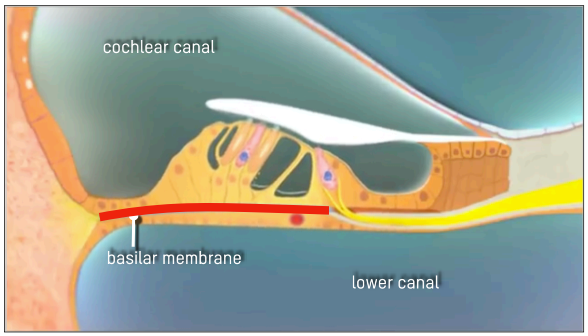
30

And about one quarter that width, about five one-thousandths of an inch across at the base, where high frequencies are transduced.



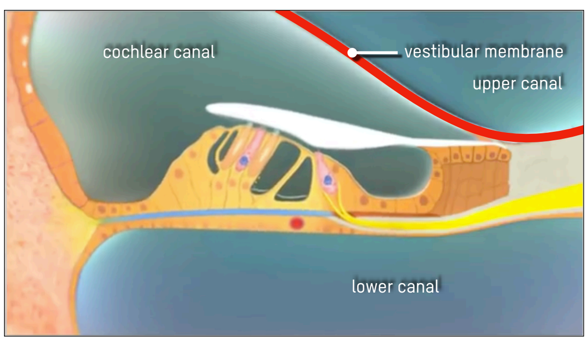
31

For reference, the width of the Organ of Corti is smaller than the diameter of the head of a typical straight pin.



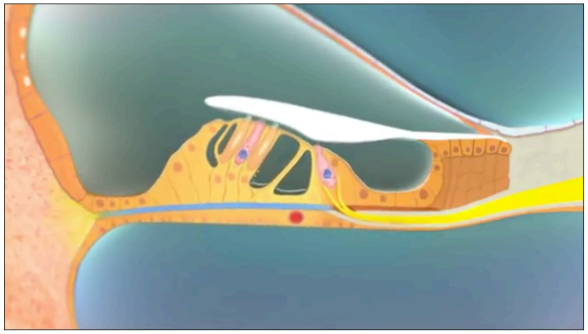
32

As I mentioned, the organ of Corti rests on the basilar membrane, which is stiffest at the base of the cochlea and most flexible at the top.



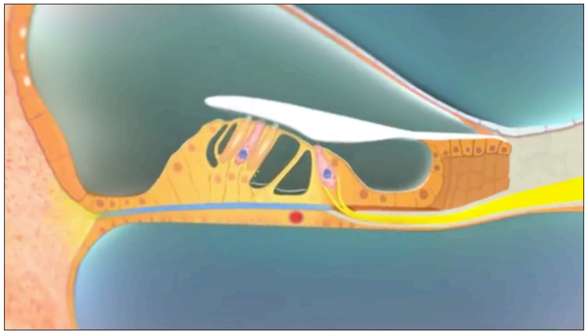
33

Deflections in the flexible vestibular membrane activate movement by the organ of Corti, which in turn deflected the basilar membrane. Let’s watch.



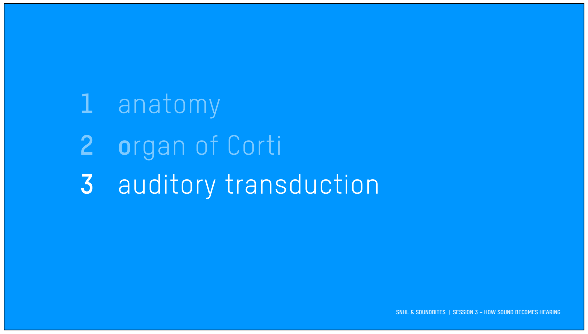
34

[video clip]



35

The vibrations can be very fast. Let’s watch again…

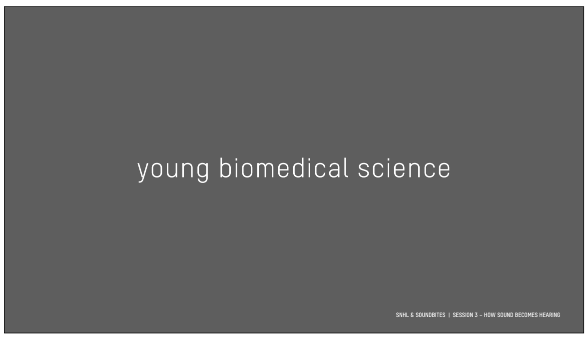


36

Now we’ll learn about how that movement initiates auditory transduction.

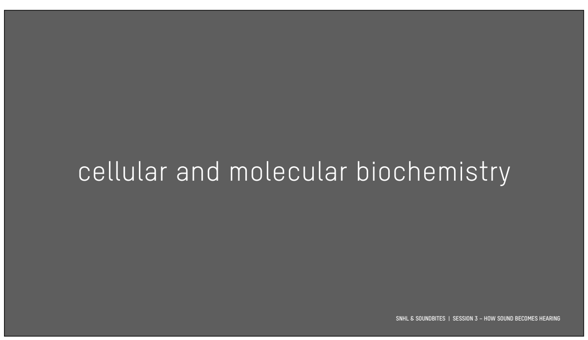
37

This is where auditory neuroscience starts.



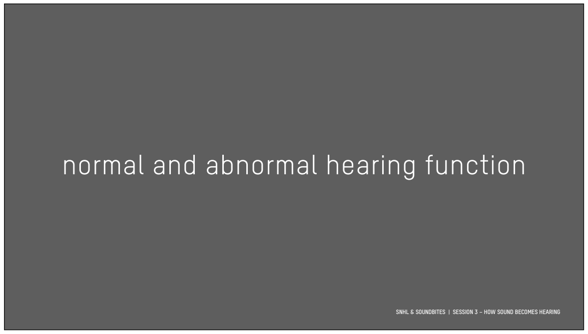
38

First, a little background. Auditory neuroscience is a relatively young branch of biomedical science within the field of biochemistry.



39

Biochemistry combines biology and chemistry to investigate and understand the chemical processes of life. The term biochemistry was first used in 1858, in Vienna. The general field is now called life science.



40

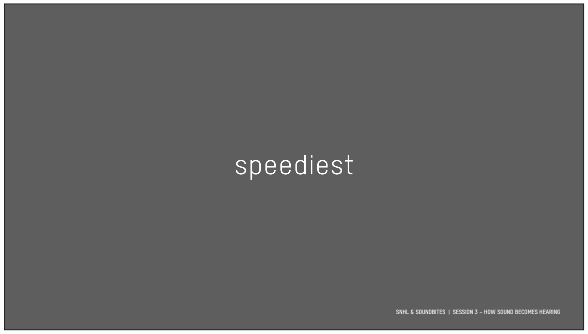
Auditory neuroscience investigates the normal biochemical processes that create hearing, and the abnormal processes, or pathophysiology, that contribute to SNHL.

41

The organ of Corti has evolved over a 250 million-year timespan in mammals and other species. It involves complex biochemistry that is still not fully understood.

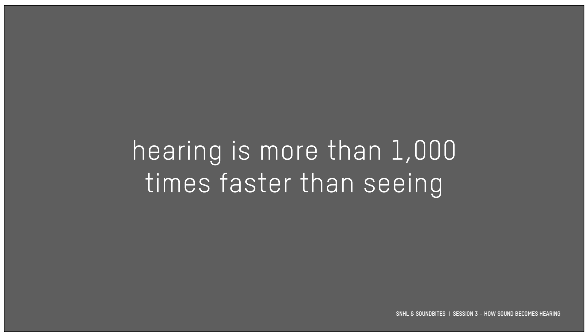
42

The organ of Corti is an exquisitely sensitive metabolic sensory system.



43

Hearing is the speediest metabolic sensory system in humans. Second place isn’t even close.



44

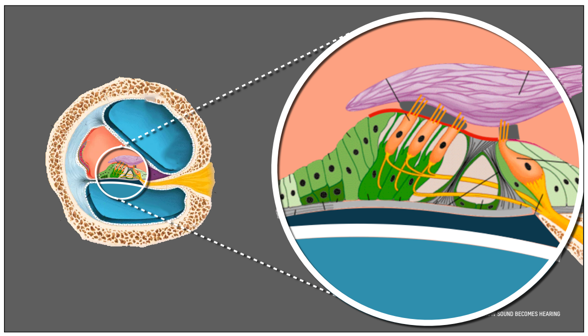
Auditory nerve cells transduce sound waves in microseconds, more than a thousand times faster than the tens of milliseconds it takes photoreceptor neurons to transduce visible light waves into eyesight.

45

Guinea pigs and humans have similar hearing physiologies and metabolic systems. For example, most animals make vitamin C, but guinea pigs and humans don’t.

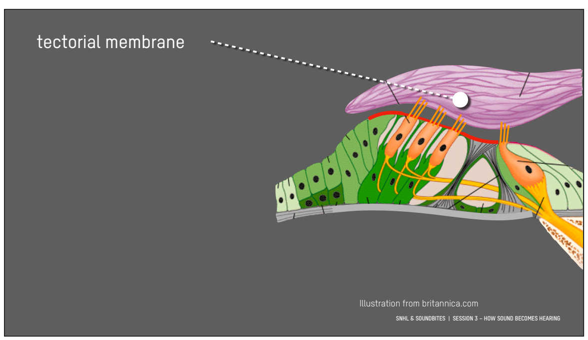
46

We owe guinea pigs a big debt of gratitude for teaching us a great deal of what we know about human hearing.



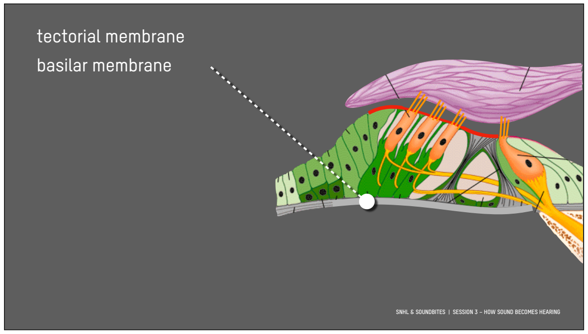
47

Let’s explore the cell structure and physiology of the organ of Corti associated with auditory transduction by zooming in on a higher-resolution illustration.



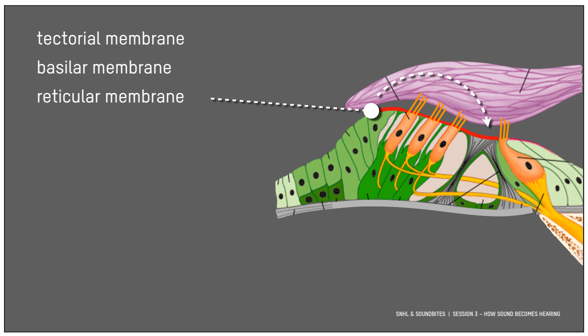
48

The tectorial membrane, or covering membrane, is at the top.



49

As we know, the organ of Corti rests on the basilar, or bottom membrane. And as we saw earlier, **auditory transduction starts when pulsations of the oval window create movement in the perilymph above and below the endolymph in the organ of Corti.**



50

The reticular membrane separates the endolymph from the perilymph. It spans the three rows of outer hair cells, in orange,

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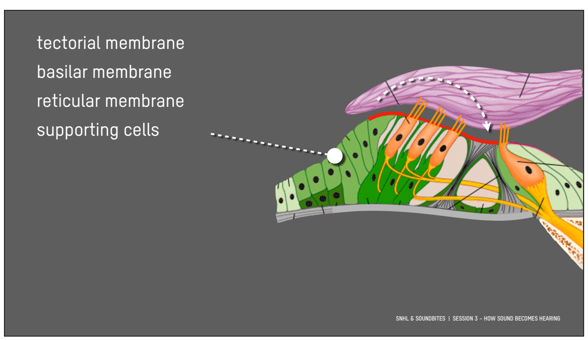
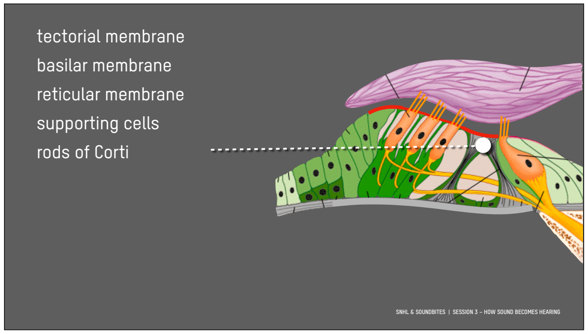


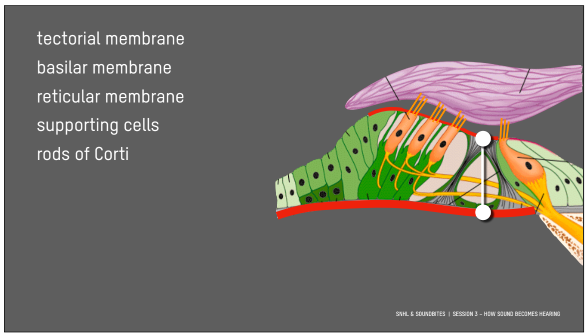
51

starting from the supporting cells, in green. This group of about half a dozen different cell types are critically important to cochlear development and function.



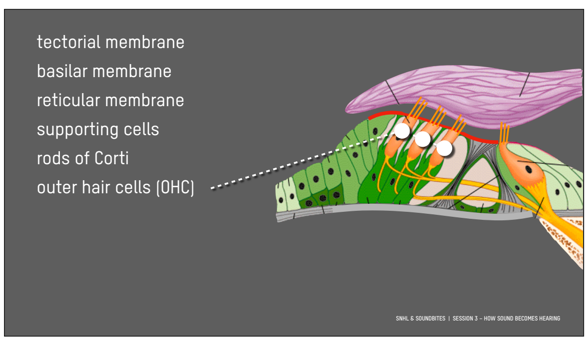
52

The reticular membrane terminates at the rods of Corti, in grey below the white dot.



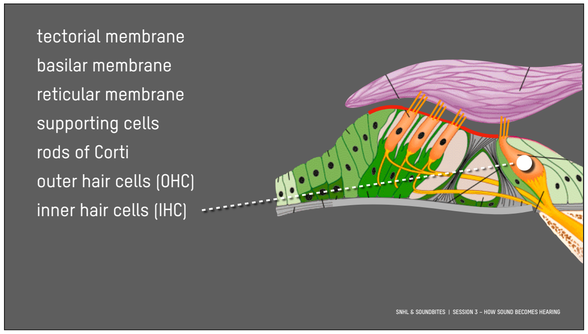
53

The rods of Corti connect the basilar membrane with the reticular membrane…



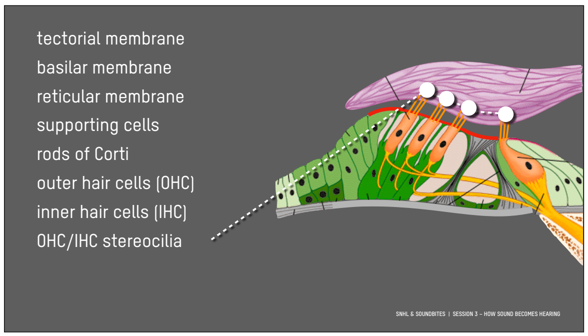
54

isolating the movement of the outer hair cells, abbreviated OHC. The OHCs are arranged in three rows. The outer hair cell bodies, indicated by the white dots, are integrated with their stereocilia extensions (the hairs of hair cells), located between the supporting cells and the rods of Corti. Humans have about 12,000 outer hair cells in each ear at birth. **Outer hair cell bodies are surrounded by perilymph. Their action is stimulated by the basilar membrane.**



55

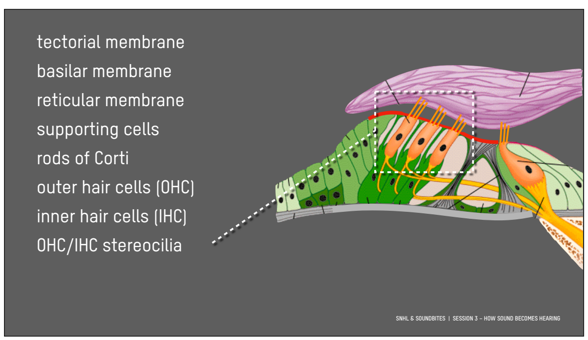
Outer hair cells transfer signals to the inner hair cells, abbreviated IHC. Humans have about 3,500 inner hair cells in each ear at birth.



56

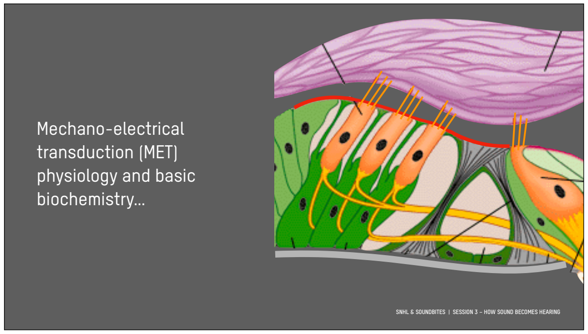
Stereocilia extensions of the outer hair cells join the outer hair cell bodies at their apex. The extensions pass through openings in the reticular membrane and into the tectorial membrane. Hearing in all mammals depends on stereocilia oscillation.

**Outer hair cell stereocilia extensions are in the endolymph, while the outer hair cell body is in the perilymph. This is biochemically important. **



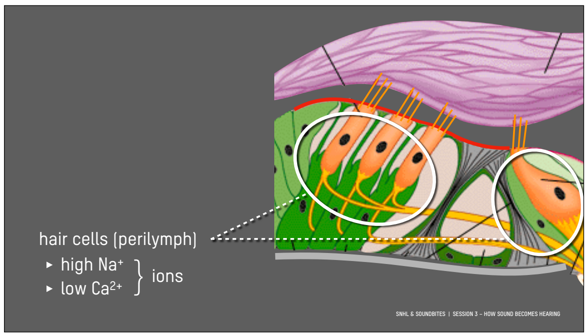
57

These bundles of highly sensitive receptor and amplifier outer hair cells are responsible for converting sound waves into their equivalent electrical impulses and separating them into their component frequencies. The process is called mechano-electrical transduction, or MET.



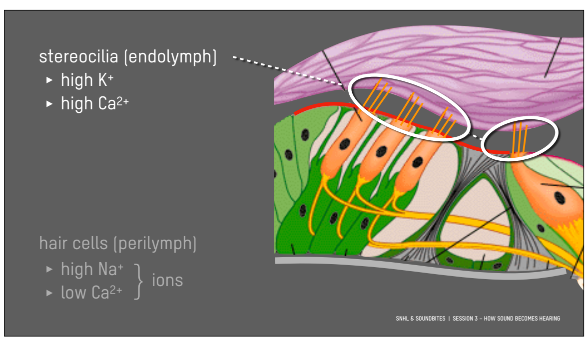
58

Let’s take an even closer look at MET physiology and its basic biochemistry.



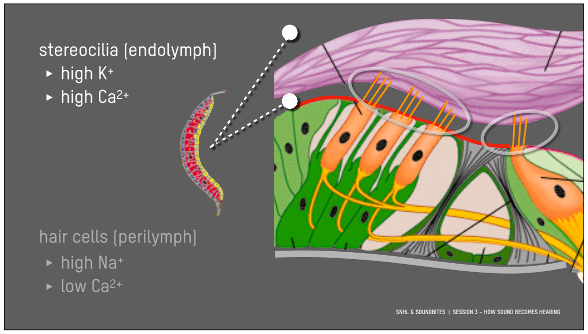
59

The perilymph surrounding the hair cells has high concentration of sodium ions and low concentration of calcium ions. Ions are electrically charged molecules.



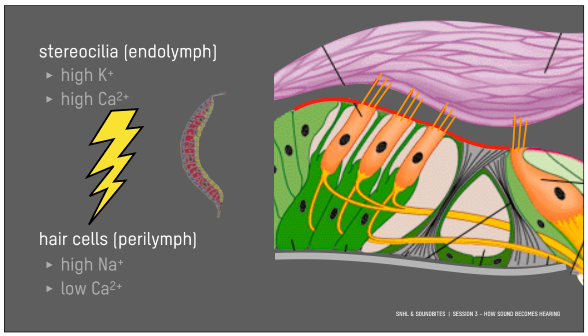
60

Stereocilia extensions are surrounded by endolymph, which has a high concentration of potassium and calcium ions.



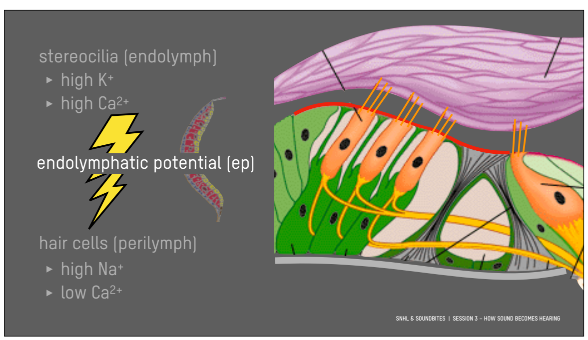
61

Recall that endolymph is secreted into the cochlear canal by the stria vascularis.



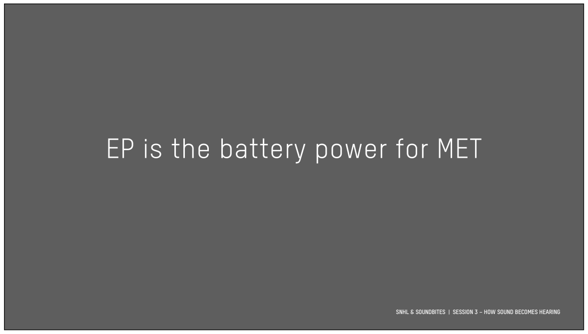
62

The difference in the ionic composition of the perilymph and endolymph creates a large difference in electric voltage between cochlear compartments. Voltage is the pressure that pushes charged electrons through a conducting loop.



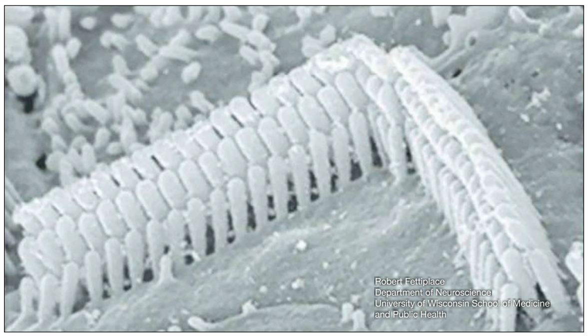
63

Electrical voltage of the endolymph in the organ of Corti is expressed as endolymphatic potential, or EP.



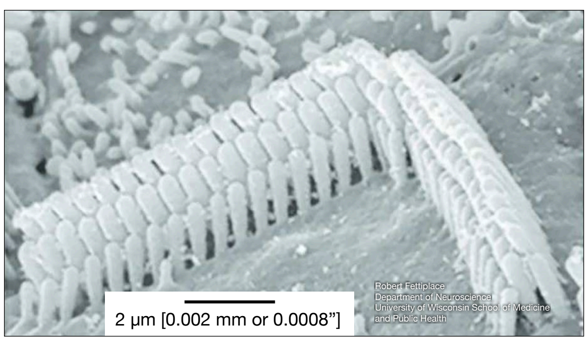
64

EP is the battery power for MET. Let’s zoom in for a very close look at the stereocilia to see how MET operates.



65

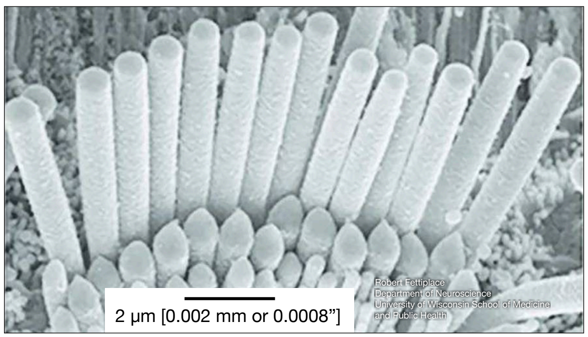
This electron scanning micrograph of outer hair cell stereocilia is from Dr. Robert Fettiplace’s research at the University of Wisconsin.



66

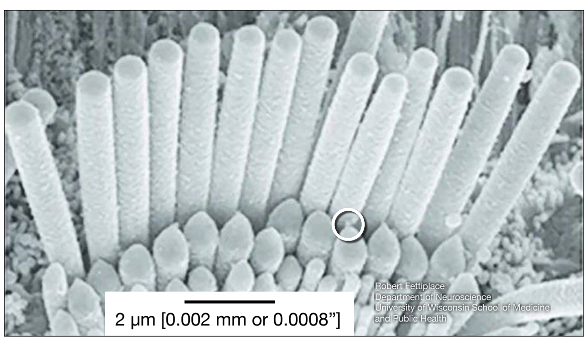
The measurement is in micrometers – one millionth of a meter, or one thousandth of a millimeter. In this case the black reference line is two thousandths of a millimeter, or 8 one hundred thousandths of an inch. Outer hair cell stereocilia are now known to be arranged in three V-shaped rows. The number of stereocilia increases and their length decreases from the top of the cochlea, where low frequencies are transduced, to its base, where high frequencies are transduced.

Auditory transduction receptor cells are exquisitely sensitive. 100 times more sensitive than receptor cells in the skin for example.



67

This micrograph of the inner hair cell stereocilia at the same scale shows their staircase arrangement. MET channels in the stereocilia open when the bundle bends toward the taller edge, and they close when the bundle bends the other way.



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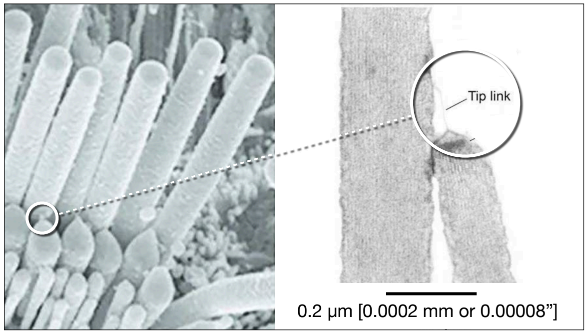
Now we’ll look at the physiology and biochemistry associated with that bending.



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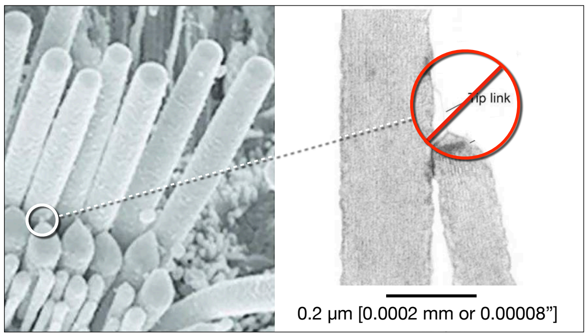
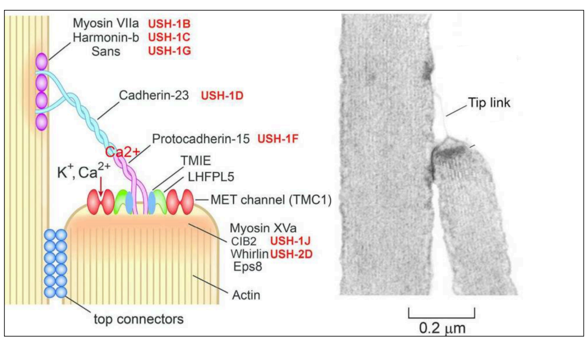
We’re now looking at a micrograph of a stereocilia tip link. Note the magnification has increased tenfold, and the tip link is barely visible. The reference line is two ten-thousandths of a millimeter, or 8 millionths of an inch.

Paraphrasing Dr. Fettiplace, tip links extend from the tip of one stereocilia extension to the side wall of its taller neighbor. They’re essential for applying force to the MET channels.



70

Tip link destruction totally eliminates transduction.



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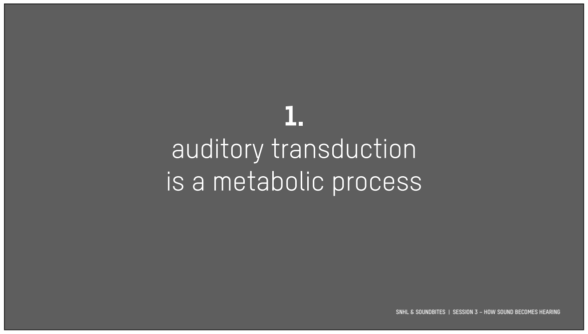
The biochemistry of auditory transduction diagrammed here by Dr Fittiplace is a unique and elegantly complex example of metabolism.

The open access Fittiplace article is included in the additional reading If you’d like to learn more about MET.



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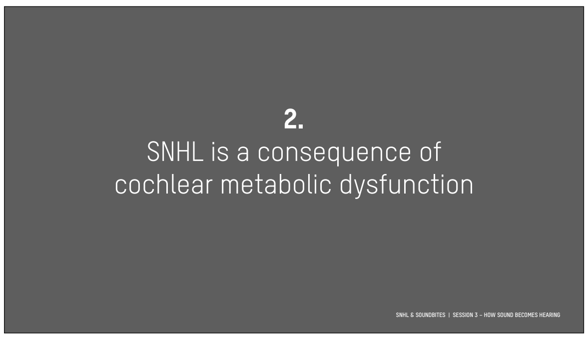
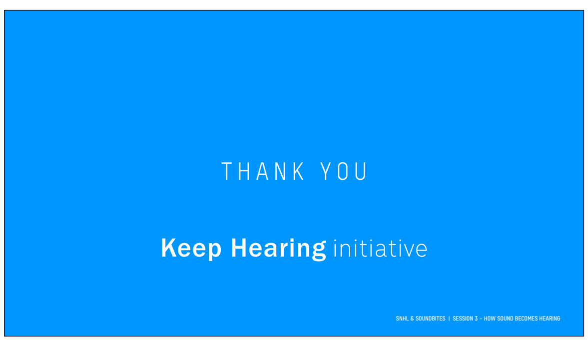
This session has two take-home messages. First, auditory transduction is a metabolic process.



73

Second, SNHL is a consequence of cochlear metabolic dysfunction.



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In the next session we'll cover the research on cochlear metabolism and metabolic dysfunction. I hope you'll join me to learn what happens when auditory transduction goes wrong and how Soundbites was developed.