Don’t Stick That In Your Ear!

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4 April 2003

ABSTRACT:

The purpose of our presentation was to teach the Neuroscience concept of audition while focusing on the function of the tympanic membrane to a group of 5th grade students. The presentation incorporated the use of a poster board containing diagrams of the outer, middle, and inner ear anatomy as well as a model eardrum made out of cellophane stretched over the opening of the bowl and a subwoofer that would vibrate the eardrum model and cause dried rice scattered on the surface to jump. Our presentation demonstrated the principle that sound takes the form of pressure waves which can mechanically vibrate the eardrum and begin the process of audition. Additionally, we demonstrated the condition resulting from a perforated tympanic membrane as we allowed a students to poke a hole in the model eardrum and then subject the model to the same auditory stimulus. Our results indicated that our kid judges understood the concepts we were teaching and thoroughly enjoyed our exibit.

INTRODUCTION:

Sound is the compression and rarefaction of air, or, in other words, alternating air pressure; and the ear is able to detect sound due to the changes in air pressure that occur as a sound source vibrates. The frequency of the vibrations depends on the distance between successive patches of dense air (sound waves). In humans, the ear can detect pressure waves in the range of 20 to 20,000 Hz. The higher the frequency of sound waves, the higher the pitch is detected. Additionally, sound can vary in intensity, which is interpreted as loudness.

The human auditory system depends on the combination of the outer ear (pinna and auditory canal) which collects sound, middle ear (tympanic membrane and ossicles) which transfers sound, and the inner ear (oval window and cochlea) which transduces the sound. In audition, air molecules under pressure cause the tympanic membrane to vibrate. Low frequency sound waves produce slow vibrations and high frequency sounds produce rapid vibrations. These vibrations move the malleus on the other side of the membrane, which in turn strikes the incus causing it to vibrate. The vibrating incus moves the third ossicle (stapes) and causes it to vibrate the oval window. Through the lever like action of the ossicles, the total force of the sound wave is transferred to the oval window, but because the oval window is much smaller, the force per unit area is increased 15-20 times (Tonndorf and Khanna). This is necessary because the fluid in the inner ear is more difficult to move than air and thus sound must be amplified.

The sound waves that reach the inner ear through the oval window set up pressure changes that vibrate the perilymph in the scala vestibuli. Vibrations in the perilymph are transmitted across the vestibular membrane to the endolymph of the cochlear duct and also up the scala vestibuli and down the scala tympani. The vibrations are transmitted to the basilar membrane which in turn vibrates at a particular frequency, depending upon the positions along its length. The cilia of the hair cells, which contact the overlying tectorial membrane, bend as the basilar membrane vibrates. This action opens ion channels and causes the entry of ions into the hair cell and a generator potential develops. If large enough, the generator potential causes transmitter release from the hair cells to excite the afferent cochlear nerve (Holton and Hudspeth).

The structure of the basilar membrane in the cochlea allows for the discrimination of different sound frequencies. The basilar membrane is narrow and stiff at the window end and wide and flexible at the apical end. This natural topographical difference in structure results in different regions vibrating at different resonant frequencies. The end near the stapes (oval window end) vibrates at high frequencies whereas the apical end vibrates at low frequencies. Information about the vibration at different locations along the basilar membrane is relayed to the auditory cortex, located in the superior temporal gyrus, by the nerves synapsing with the hair cells at those locations. The auditory cortex is said to be tonotopically mapped, whereby the basilar membrane is represented point for point on the auditory cortex (Holton, and Hudspeth).

Much of the focus of our neuroscience model dealt the function of the tympanic membrane because it the first structure involved in audition and it is a common site for injury. The tympanic membrane is located in the auditory canal and separates the outer ear from the ossicles of the middle ear. It functions not only as a physical barrier to foreign material and bacteria, but also as large receptive surface that vibrates in response to sound pressure waves and relays the vibrations to the ossicles. It is a thin semitransparent, oval-shaped membrane and is often called the “eardrum” because it resembles the skin stretched across a drum.

The tympanic membrane may be perforated by acoustic trauma such as puncture by a Q-tip, bobby pin, or from an open-handed slap to the ear. It may also be ruptured by barotraumas, which is pressure induced damage commonly associated with scuba diving. However, the most common cause of rupture is from ear infections which cause increased fluid and pressure in the middle ear. Conversely, a perforation of the tympanic membrane may lead to infection because bacteria can enter through the hole and infect the middle ear.

Besides the prospect of infection, perforation of the tympanic membrane reduces the ear’s ability to detect and transmit the mechanical energy associated with sound pressure waves. The symptoms of a perforated tympanic membrane include hearing impairment and tennutis, resulting from the diminished ability of the tympanic membrane to vibrate and transfer vibration to the ossicles. Many perforations will heal spontaneously, in much the same manner that a small cut on the skin would heal. However, some severe cases require surgical repair of the hole in a procedure called tympanoplasty (Fernandez et al).

METHODS:

Our goal was to demonstrate the function of the tympanic membrane and the general process of audition. Therefore we began our project and presentation by tracing the auditory pathway from the outer ear to the brain cortex. This was accomplished by using a poster containing diagrams of different parts of the anatomy of the ear and explaining the related background details.

The first picture on the poster diagramed the entire ear including the outer, middle, and inner ear sections. We used this picture to trace the general path that sound travels in the ear; collection by the auricle, passing through the auditory canal, vibration of the tympanic membrane, vibration of the ossicles, and finally reception in the cochlea.

The second picture diagramed the cochlea and illustrated the different functional regions of the basilar membrane in an uncoiled representation. We used this picture to explain how different parts of the inner ear organ are tuned to detect different frequencies. In order to better illustrate this point, we cut the spikes of a hair comb at a diagonal so that one end of the comb retained the longest spike and the opposite end possessed the shortest spike. The varying lengths of spikes represented the different hair cells tuned to different frequencies along the length of the basilar membrane.

Next we explained how nerve fibers from specific hair cells on the basilar membrane project to specific parts on the cerebral cortex, noting the preservation of organization (tonotopy). A picture of a brain illustrated this concept with the region associated with auditory perception highlighted (superior temporal gyrus) and partitioned in sections associated with different frequency perception. To hammer down the concept of tonotopy, six segments of the comb were painted using different colors and then the primary auditory cortex was painted with the same six colors. By painting different parts of the comb and different parts of the cortex with the same corresponding color, we were able to visually demonstrate the concept that frequency organization is preserved in the brain.

The second part of our presentation focused on the action and function of the tympanic membrane. Our goal was to demonstrate that the eardrum is very similar to a thin membrane, and that sound takes the form of pressure waves capable of vibrating the eardrum and initializing the auditory process. We thereby constructed a model eardrum using a large bowl and cellophane stretch over the opening. Next, in order to demonstrated that sound takes the form of pressure waves, and pressure waves vibrate the membrane, we scattered dried rice over the stretched cellophane and subjected the apparatus to an auditory stimulus. Our auditory stimulus consisted of a THX Lucusfilm surround-sound-test played from a laptop computer. The laptop speakers were incapable of producing a sound intensity sufficient to deflect our model eardrum, so the computer was connected to an amplifier which drove an 8" subwoofer. Playing of the surround sound note through the subwoofer caused the model eardrum to vibrate, as reflected by the jumping rice. We repeatedly played the surround sound note at different sound intensities and asked the kids the note the difference in the height of the jumping rice.

Once we felt comfortable that the kids had grasped the concept of the tympanic membrane, we moved on to explain and demonstrate the auditory symptoms associated with injury to the eardrum. For this, we asked one of the kids to poke a hole in the eardrum model and then we again played the surround sound note and watched the rice jump. After this demonstration, we asked the kids to summarize what they had just witnessed. We then concluded our presentation by explaining the clinical consequences of sticking objects too far in your ear and used references to our demonstration in our reasoning.

RESULTS:

The scores and comments that we received from the kids indicated that we were successful in our presentation. The kid judges voted us as their favorite exhibit on side B, and their loud applauses and cheers after we were announced as the winners showed that we were well received. In addition to the kids' overall favorite vote, we were evaluated on 4 quantitative questions and 2 general questions. The average scores for the 4 quantitative questions are as follows (scale from 1-5):

1. Could you understand what the presenters were trying to tell you?	4.81
2. Were the presenters friendly?	4.87
3. Was the exhibit fun?	4.60
4. Would you like to learn more about this topic?	4.08
Combined average for all four questions	4.59

These results are fairly consistent with the final placing as our combined average score (4.59) was second to the highest combined average score (4.67) with an overall correlation of –0.62.

The general question: what was your favorite part of this exhibit, was almost unanimously answered with the statement "watching the rice jump when they turned on the speaker" or "poking a hole in the model eardrum". The question: what did you learn from this exhibit, elicited a wider range of answers and included:

1. Sticking things too far in your ear could pop your eardrum
2. Different parts of the ear pick up different pitches
3. Sound pushes air
4. Sound vibrates the eardrum
5. Louder sound causes the rice to jump higher

The success of our presentation and demonstration was also evaluated by other means. Participation was high during the entire presentation reflecting their interest, and their quick and thoughtful answers to our questions showed that they understood the information we were presenting.

DISCUSSION:

Based upon the Kids' Judge evaluations and the kids' participation during the presentation, I feel that we were successful in accomplishing our goals of demonstrating the function of the tympanic membrane as well as the general auditory process. I feel that the technical appearance of our demonstration was a large factor in gaining the kids' initial attention. Upon approaching our exhibit, they immediately gathered around the speaker and model eardrum in order to get the best viewing position.

As we began our presentation by describing the auditory pathway and explaining tonotopy, it was apparent that the kids were anxious for us to move on to the demonstration. Very few questions or side comments were made during this time. Sensing a growing loss in attention, we quickly moved on to the demonstration and opted to forego further explanation of tonotopy by using the analogy of the painted hair comb and painted brain region. This proved to be a wise decision because an extended explanation of tonotopy would have consumed too much time and caused us to cut our demonstration short.

Things quickly changed when we moved onto our demonstration of the tympanic membrane. The silence that overcame the groups quickly fled as the surround sound note resounded. The kids excitedly cheered and awed as the rice jumped and instantly appeared interested in whatever we had to say. Asking them to compare the height of the jumping rice with the intensity of the sound led them to produce comments that reflected their understanding that a more intense the sound causes the tympanic membrane to vibrate more.

After explaining the scenario in which an individual pushed an object too far into their ear and popped their eardrum, we asked them what they thought would happen. Majority of the comments expressed the idea that one would no longer be able to hear. So next we let one of the kids poke a hole in the model eardrum with their pencil and then subjecting the membrane to the same sound stimulus and observed the behavior of the rice. Afterwards, we asked them if they still thought an individual would be able to hear. Most that responded said that the rice still jumped but not as high as before; so an individual suffering from a hole in their eardrum could still hear, but not as well.

Their answers to our questions and interest in our demonstration indicated that we were successful in teaching the Neuroscience principle audition in a fun manner. However, I feel that we could have benefited from a little more time. More time to present would have enabled us to further delve into the process of audition and demonstrate other symptoms associated with tympanic membrane damage.

References

1. Fernandez et al. Traumatic Perforations of the Tympanic Membrane. Journal of Louisiana State Medical Society 2001 Mar; 153(3): 116-118.

2. Holton T. and Hudspeth AJ. A Micromechanical Contribution to Cochlear Tuning and Tonotopic Organization. Science 1983 Nov; 222: 508-510.

3. Tonndorf J. and Khanna SM. The Tympanic Membrane in Middle Ear Transmission. Acta Oto-Laryngologica 1971 Feb-Mar; 71(2): 177-80.