ARMY RESEARCH LABORATORY

Auditory Demonstrations for Science, Technology, Engineering, and Mathematics (STEM) Outreach

by Ashley N Foots, Jeremy R Gaston, Kimberly A Pollard, and Timothy J Mermagen

ARL-SR-0306 **January 2015**

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Human Research and Engineering Directorate, ARL

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14. ABSTRACT
The US Army Research Laboratory (ARL) participates in science, technology, engineering, and mathematics (STEM) outreach programs, including the Gains in the Education of Mathematics and Science (GEMS) program under the Army Educational Outreach Program. During GEMS, ARL provides STEM instruction and lab demonstrations to visiting groups of students ranging from fifth graders through high school graduates. This report documents the involvement of ARL's Human Research and Engineering Directorate's Perceptual Sciences Branch (PSB) in the 2014 GEMS program and provides detailed descriptions of lecture materials, slides, and hands-on demonstrations that were used. PSB provided education through lecture and demonstrations on 3 auditory topics: 1) the anatomy and physiology of hearing and hearing conservation, 2) acoustic resonance, and 3) bone conduction. Students learned about how the ear works, what listening levels are safe, how objects such as musical instruments or the vocal tract resonate with sound, how sound can travel through bones, and when bone-conducted hearing is used. Demonstrations included measuring earbud output levels on an acoustic test fixture, visualizing resonance nodes with a Chladni plate, and listening to sounds through bone conduction headsets.

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Contents

List of Figures

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1. Introduction

The US Army Research Laboratory (ARL) participates in an outreach program called Gains in the Education of Mathematics and Science (GEMS), which is under the Army Educational Outreach Program. The objective of GEMS is to support students with education in areas of science, engineering, mathematics, computational sciences, computation biology, biomedical sciences, chemistry, and biology. GEMS students range in age from rising fifth graders to high school graduates. The students visit ARL facilities and engage in hands-on learning in the laboratory. The students are exposed to many aspects and applications of mathematics and science that they would not typically have the opportunity to learn about in school. GEMS sessions are week-long programs where students visit different labs on different days. At the end of the week, students present a PowerPoint presentation on one of the topics that they learned about during the week. In 2014, ARL's Human Research and Engineering Directorate (HRED) hosted one of these lab days biweekly for 8 weeks.

ARL/HRED's Perceptual Sciences Branch (PSB) provided GEMS student learning experiences in 3 topic areas: 1) anatomy and physiology of hearing with a special focus on hearing conservation, 2) acoustic resonance, and 3) bone conduction hearing. There were 3 groups of students each week, and each group was provided with approximately 1 h of instruction. The 1-h session was divided into 2 main parts. The initial part consisted of a PowerPoint presentation introducing all of the background information for the 3 topics (PowerPoint slides and student worksheets are included in the Appendix). In the second part, students were organized into 3 groups to rotate through the interactive stations related to each topic. The 3 stations included 1) a preferred listening level station, 2) a Chladni plate station, and 3) a bone conduction station. Hands-on, interactive demonstrations were provided at each of the stations. The students received handouts that included the PowerPoint presentation and worksheets for each station so they could fill in information about the demonstrations. The purpose of the worksheets was to allow students to write down notes about their experiences and keep the students engaged in the activities. Additionally, ARL requires GEMS students to complete a presentation at the end of the GEMS week, and the handouts and worksheets also help students take notes for their presentation. The presentation is 1 or 2 slides summarizing one of the topics that the students participated in during the week. The students are assigned a specific topic by GEMs coordinators so that all students do not present on the same topics. Descriptions and procedures followed at each station are provided in subsequent sections, including the information told to the students by the instructors.

In designing the learning topics, the goal was to create lecture and demonstration materials suitable for all ages within the GEMS program. Also, it was important to make the complex scientific topics relatable and understandable to an audience that has limited or no background knowledge of the topic areas. Each presenter was encouraged to give background information on their education and current positions to inspire students to become interested and learn more about careers in mathematics and science. Previous GEMS students have gone on to work with ARL as interns through college and graduate school. In addition, some are now employed by ARL.

2. Researchers and Responsibilities

Ashley Foots conducted the presentation on the anatomy of hearing and hearing conservation. She also assisted at the preferred listening level station to help students calculate and discuss recommended exposure times based on their preferred listening level for music. Jeremy Gaston presented the topic on acoustic resonance and was the instructor at the preferred listening level station. Kimberly Pollard presented the topic on bone conduction and was the instructor at the bone conduction station. Tim Mermagen helped develop the instruction materials and equipment used for the listening level station and the Chladni plate station, and he was the instructor at the Chladni plate station. Miller Roberts assisted Tim Mermagen in the equipment setup and was the assistant instructor at the Chladni plate station. Finally, Kelly Dickerson served as an assistant instructor at the preferred listening level station.

3. Learning Topics

The leaning topics are organized into several sections. First, a general overview is given followed by the lecture background section. The majority of the lecture background section is in present tense because it represents information as the lecturer presented it to the students. In addition, this information has been indented to differentiate it from background and procedural details important to the reader. The lecture background information is followed by a description of materials and procedures important to the associated interactive topic station. Again, relevant information presented to the students by the lecturers has been indented to differentiate it from procedural details.

3.1 Topic 1: Anatomy of Hearing and Hearing Conservation

The topic on anatomy and physiology of hearing included overviews of the auditory pathway, hearing conservation, and the types and use of hearing protection devices. The related interactive topic station was an activity that allowed students to adjust the sound level of music to their preferred listening level using a portable media player. The preferred listening level was then compared to the recommended exposure limits discussed in the lecture.

3.1.1 Lecture Background

The following information was presented to the students by the lecturer to provide background information about the topic:

> Sound waves travel down the ear canal and vibrate the eardrum [Gelfand 2009]. Once the eardrum is vibrated, it sets the ossicular chain in motion. The ossicular chain consists of 3 small bones in the middle ear: the malleus (hammer), incus (anvil), and stapes (stirrup). The foot plate of the stapes then presses on the oval window of the cochlea causing the fluid in the cochlea to move. The fluid in the cochlea creates tension differences which cause the fine structures of the hair cells in the cochlea to move. The hair cells for high frequencies are closest to the base of the cochlea and the hair cells for low frequencies are closest to the apex of the cochlea. Mechanical energy is transformed into electrical signals that are then sent to the brain. The brain then recognizes the signal as speech, music, etc. An anatomical diagram of the auditory system can be seen in Fig. 1. Now I am going to show you a short video that shows how a sound moves through the auditory pathway.

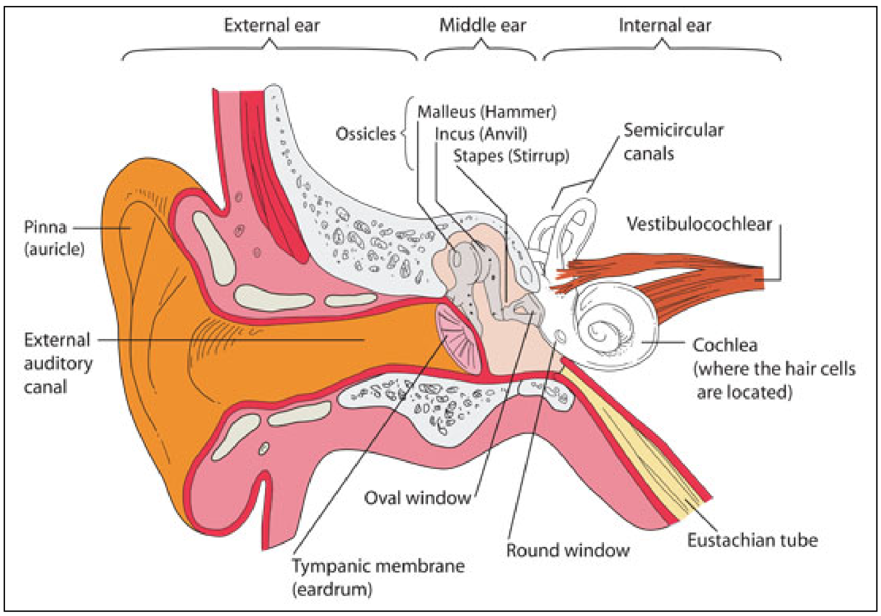

Fig. 1 Anatomy of human ear. (Permission to reprint given by Dangerous Decibels on September 10, 2014. Image retrieved from http://www.dangerousdecibels.org/education/information-center/how-we-hear/.)

Students were then shown a short video that gave an excellent description of the auditory pathway (http://www.youtube.com/watch?v=flIAxGsV1q0), followed by a second video that demonstrated how individual hair cells work (http://auditoryneuroscience.com/ear/dancing_hair_cell).

A second video demonstrates how individual hair cells work. This video is of an individual outer hair cell from a guinea pig. An electrode was attached to the hair cell and researchers used an alternating current ("Rock Around the Clock" by Bill Haley and His Comets) to stimulate the hair cell. The hair cell in the video was observed under a microscope and recorded. Typically, normal healthy hair cells are straight and stand tall [Fig. 2] whereas damaged hair cells are unable to stand straight up and down, appearing to be bent. There are 3 types of hearing loss including sensorineural, conductive, and mixed hearing loss. Damage to the hair cells is a cause of sensorineural hearing loss. Hair cells cannot be regenerated, so this damage is permanent. Conductive hearing loss occurs when there is damage or obstruction in the outer or middle ear preventing sound from reaching the inner ear effectively. This can be temporary due to fluid in the middle ear or earwax buildup in the ear canal, but it can also be permanent. A mixed hearing loss is a combination of sensorineural hearing loss and conductive hearing loss. Hearing loss can range in severity from mild to total hearing loss.

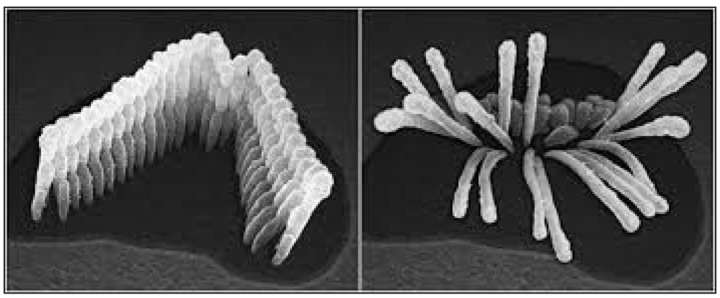

Fig. 2 Normal hair cells (left) and damaged hair cells (right). (Permission to reprint given by Dangerous Decibels on September 10, 2014. Image retrieved from http://www.dangerousdecibels.org/education/information-center/.)

Repeated or extended durations of exposure to loud sounds can cause hair cell damage and result in hearing loss. There are many situations and types of loud sounds to which individuals in modern society are typically exposed to.

Students were then provided with a "Noise Thermometer" bookmark.

This bookmark is a visual representation of various common sounds that range from soft to very loud, with the corresponding intensity level marked [Fig. 3]. Common sounds can be compared to the recommended exposure time from the National Institute for Occupational Safety and Health (NIOSH) to raise awareness of the risk of hearing damage resulting from exposure to the sounds. For instance, a leaf blower is approximately 110–115 dB. To prevent hearing damage, one should not be exposed to 115 dB for more than 30 s without hearing protection. Most people do not know how loud a leaf blower can be nor do they realize the damage that can occur to their hearing. The leaf blower is one of many examples. The recommended exposure times from NIOSH can be viewed in Fig. 4.

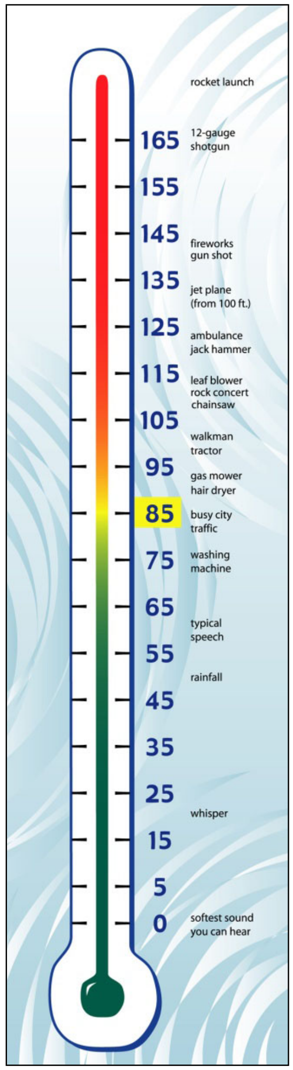

Fig. 3 Noise thermometer. (Permission to reprint given by Dangerous Decibels on September 10, 2014. Image retrieved from http://www.dangerousdecibels.org/education/information-center/decibel-exposure-time-guidelines/.)

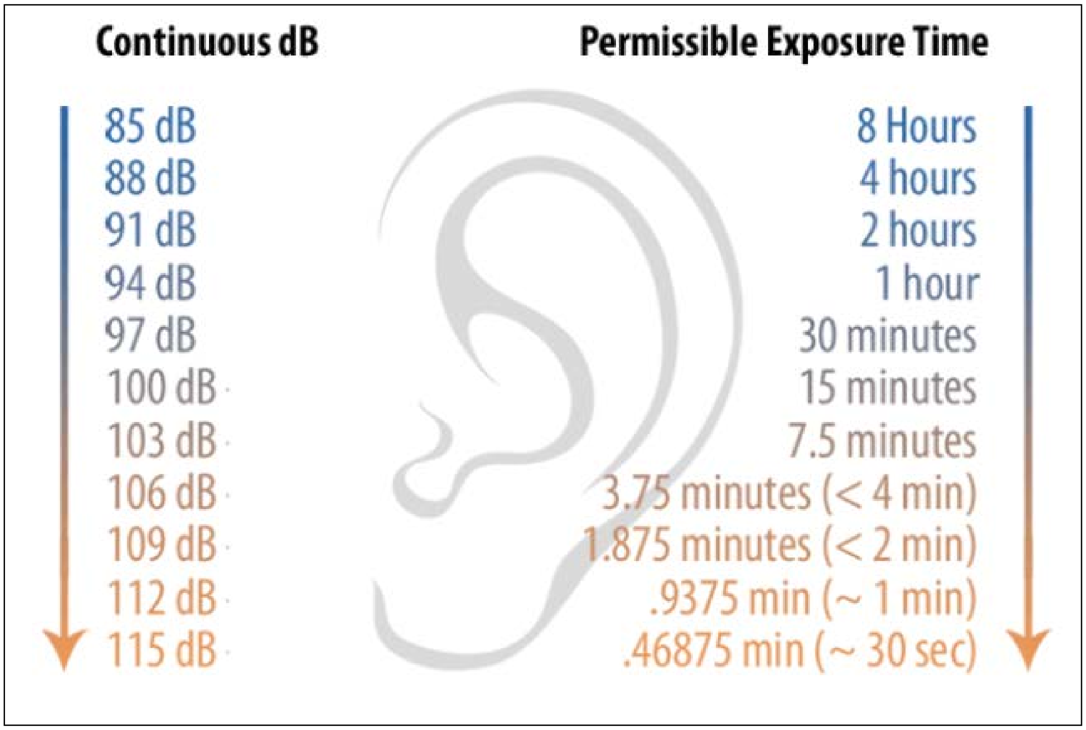

Fig. 4 Recommended permissible exposure time from NIOSH. (Permission to reprint given by Dangerous Decibels on September 10, 2014. Image retrieved from http://www.dangerousdecibels.org/education/information-center/decibel-exposure-time-guidelines/.)

Auditory hair cells do not regenerate, so by the time the damage occurs the hearing loss will be permanent. Thus, it is important to prevent hearing damage by reducing the intensity of sounds entering the auditory pathway. Hearing protection attenuates environmental sounds by reflecting or absorbing some portion of the sound waves. There are 2 types of hearing protection, over the ear and in the ear. A display of hearing protection can be seen in Fig. 5. The over-the-ear style hearing protection devices cover the entire outer ear. Over-the-ear style hearing protection devices are being used properly when the entire ear is covered by the muff and the muff creates a seal. The in-the-ear style hearing protection devices slide into the ear canal and expand. The in-the-ear style hearing protection is often more difficult to insert properly, which reduces the effectiveness. It helps to lift up on the pinna, straightening the ear canal, while inserting the compressed plug. If hearing protection is not available, then sounds should be turned down at the source. If turning loud sounds down is not an option, then walking away from the loud sound should be considered. Additional information on hearing conservation can be found at http://www.dangerousdecibels.org/.

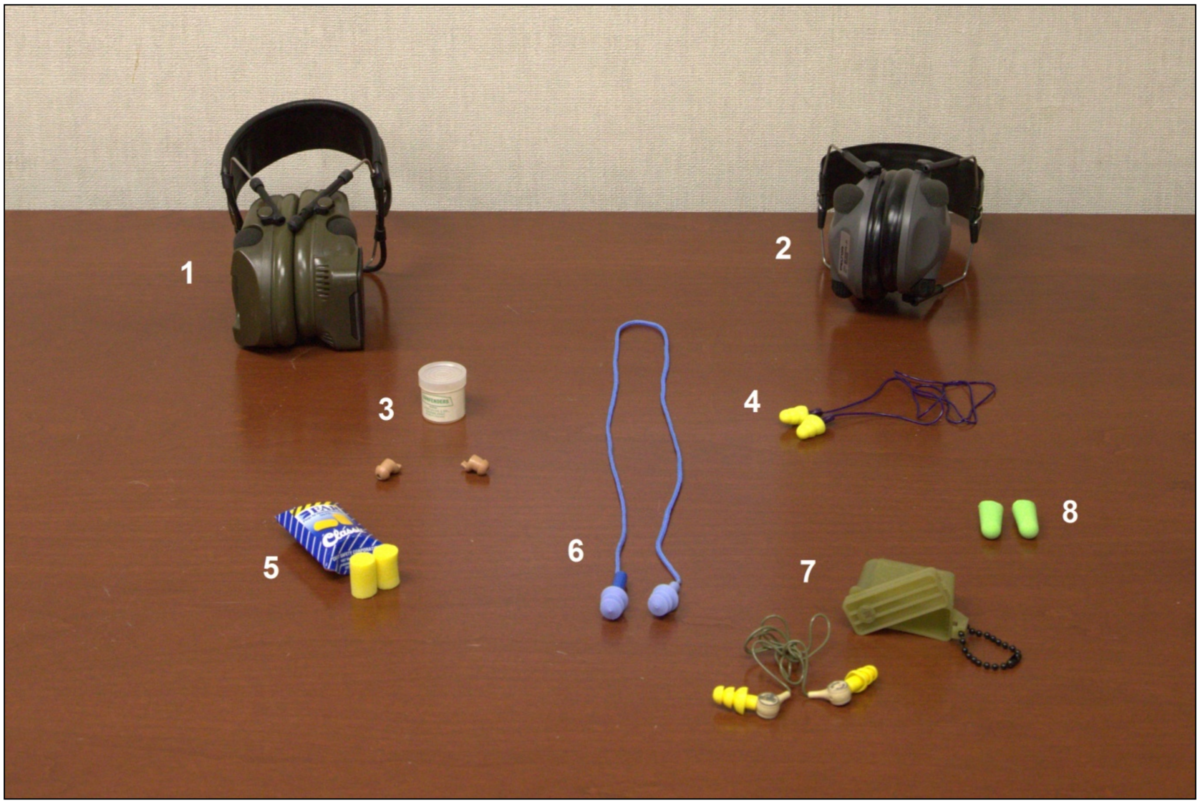

Fig. 5 ARL photo of examples of hearing protection devices including 1) Peltor supra-aural hearing protection, model MT15H68FB-03, 2) Peltor Tactical 6-S supra-aural hearing protection, 3) Gunfenders, 4) Ear Ultrafit, 5) Ear Classic foam earplugs, 6) Tasco Tri-fit, 7) Combat Arms Earplugs generation 2, and 8) Moldex Pura-fit 6800.

3.1.2 Interactive Topic Station: Preferred Listening Levels for Music

The purpose of this interactive station was to measure the potentially dangerous listening habits of students and provide information on how to protect hearing. The students adjusted a portable media player with earbuds to their preferred listening level. The students then compared their exposure level to the NIOSH-recommended sound exposure times (NIOSH 1998) for how long they could listen to sounds at that level without potentially causing permanent hearing damage. After the measurement of preferred listening levels and permissible sound exposure times, instructors provided students with strategies to protect their hearing while listening to music. For example, sound attenuating circumaural headphones or in-the-ear-canal phones can be used to reduce background noise, and reducing background noise can lead to lower preferred listening levels (Henry and Foots 2012).

3.1.3 Demonstration Equipment Setup

A portable media player was used to play a song through common earbud headphones. The selection of the song was a challenge because the song needed to be age appropriate. The song selected was “Happy” by Pharell Williams. Sound levels were measured using a Knowles Electronic Manikin for Acoustic Research (KEMAR). KEMAR is an acoustic test fixture that has 2 G.R.A.S. 26AC microphones mounted internally to 2 G.R.A.S. 711 acoustic couplers that mimic the resonances of the human ear canal (Fig. 6). Realistic pinnae, mounted to the outside of KEMAR, held the earbuds much like the human ear does (Fig. 7). The KEMAR microphones were powered by a G.R.A.S. 12AK power supply, and sound-level data were analyzed using a commercial audio program running on a laptop personal computer (PC). Calibration of the KEMAR microphones was accomplished by recording a signal through the KEMAR from a G.R.A.S. 42 AA pistonphone calibrator, which produces a 250-Hz tone at 114-dB SPL. The equipment setup can be seen in Fig. 8.

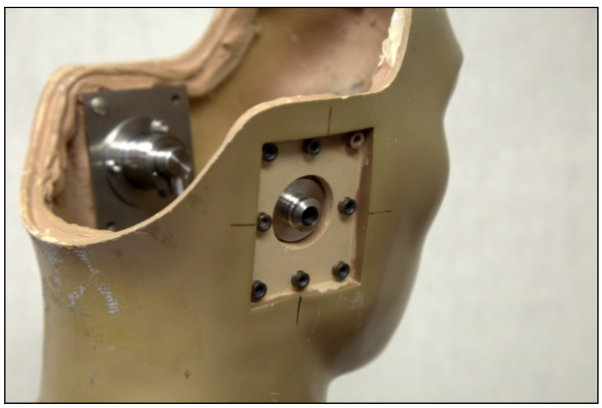

Fig. 6 ARL photo of G.R.A.S. 26AC microphones mounted internally to 2 G.R.A.S. 711 acoustic couplers that mimic the resonances of the human ear canal

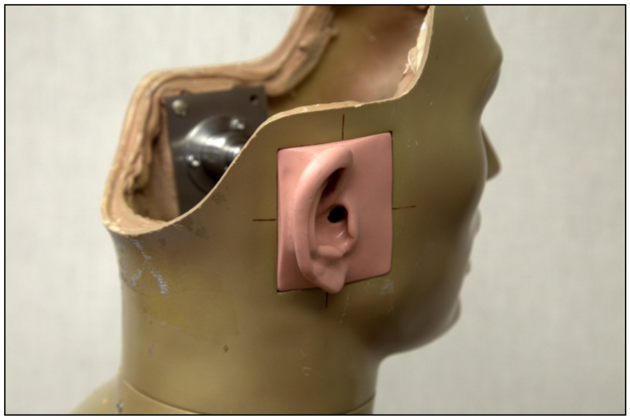

Fig. 7   ARL photo of KEMAR's realistic pinna

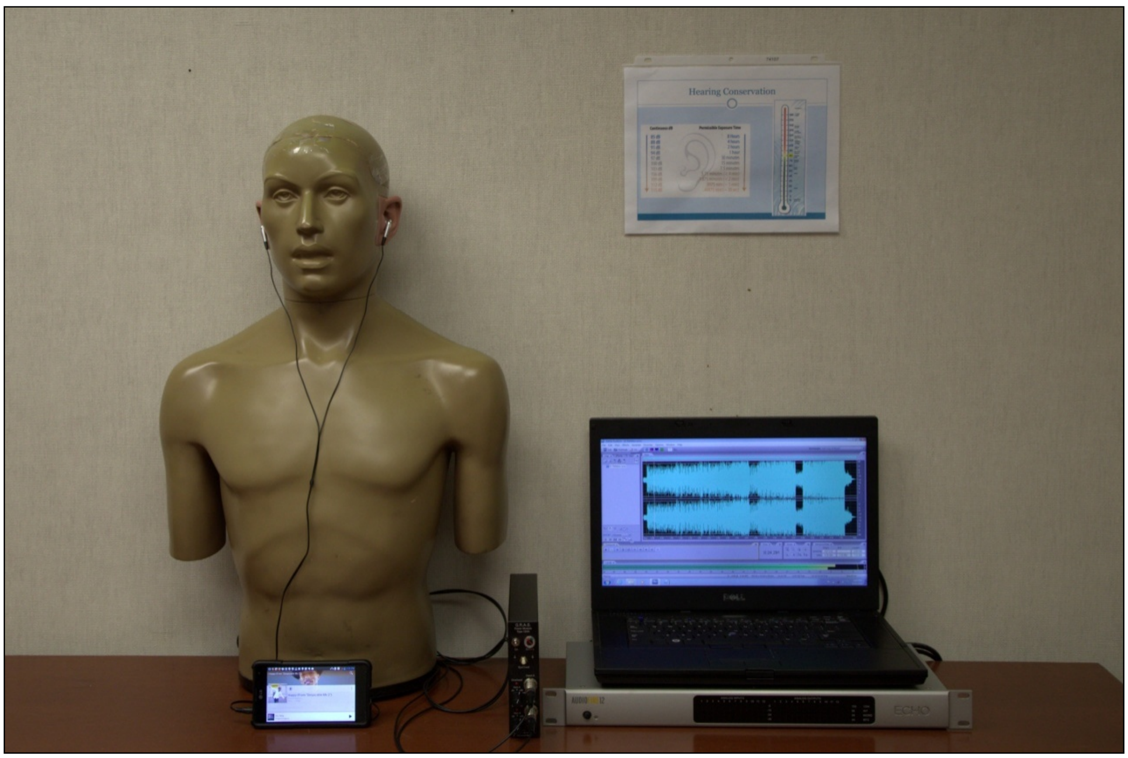

Fig. 8   ARL photo of portable media player station

3.1.4 Demonstration Procedure

Each student was first handed a new set of earbud headphones for use during the activity. Instructors then began by briefly describing KEMAR:

> KEMAR is an auditory test fixture that is used for making sound measurements, which can give researchers a good idea of what a sound may be like at the human ear. This is because KEMAR has a realistic pinna and realistic ear canal that mimic the resonances of the real human ear canal. These features alter the incoming sounds similar to the human ear before being recorded by the microphones.
>
> The microphones in KEMAR's ear canals convert the sound waves that hit the microphone diaphragm into electrical voltage. All of the components of the recording chain from the KEMAR microphones to the laptop PC represent an electrical system, and each part affects the intensity of the signal. The sound meters displayed on the laptop PC show the maximum possible level as zero, and lower levels are all negative from zero to negative infinity. The value of zero represents the maximum voltage value that can be measured by the system, and all measurements are relative to this maximum value. To convert the "relative" values to absolute measurements, calibration is completed by playing a known signal through the system and noting the relative value for that signal. This is accomplished by playing a signal produced by a sound calibrator through the system. The signal used was a 250-Hz tone at a sound pressure level of 114 dB. This known signal was used to reference all of the measurements. The sound meters will show that the calibration signal produces a relative value of –6 dB. This means that there is 6 dB of sound "headroom" before a signal would exceed the electrical maximum of the system. To compute the calibration offset value (CV_{offset}), the measured value (relative level [RL] on the computer) needs to be subtracted from the real value of the calibration signal.
>
> $$\textit{Calibration signal level} = CV_{offset} + RL$$
> $$CV_{offset} = \textit{Calibration signal level} - RL$$
>
> The actual listening level (LL) of any sound can then be calculated by adding the measured level (RL) of a played sound to the CV_{offset}:
>
> $$LL = CV_{offset} + RL$$

Students made these calculations on a provided worksheet (see Appendix, Portable Media Player Worksheet). When a student calculated their LL, they looked at the sound thermometer described in the lecture to obtain the permissible exposure time for their individual LL based on NIOSH recommendations (NIOSH 1998). Finally, the instructors discussed with students the importance of protecting their hearing and gave suggestions about ways to help limit exposure to loud music. For example, using hearing protectors or moving farther away (i.e., 6-dB-drop in sound level per doubling of distance) at concerts was discussed. When listening to portable music players, use of circumaural (over the ear), closed (sound attenuating) headphones can help reduce background sounds. This is also true of in-the-ear-canal phones, which can significantly attenuate background noise.

3.2 Topic 2: Acoustic Resonance

The topic on resonance included a discussion of acoustic resonance and examples of how changing the size, shape, and driving frequency of a sound source can result in changes in the resonant frequency. After the lecture, students participated in a hands-on activity using a Chladni plate to demonstrate the concept of resonance.

3.2.1 Lecture Background

The following information was presented to the students by the lecturer to provide background information about the topic:

> When objects vibrate, the frequency at which the maximum movement occurs is called its natural or resonant frequency. Two primary ways to change the resonant frequency of an object are to 1) change the size or shape of the object, or 2) change the driving frequency at which the object vibrates [for a speech example see Denes and Pinson 1993; for a musical instrument example see Howard and Angus 2009].
>
> One simple example of how size and shape can affect the resonant frequency is a vibrating wine glass; when the volume of air changes, so does the resonant frequency. This can be easily demonstrated by running your finger along the top of a wine glass to provide the vibration source. The frequency at which the glass resonates is related to the volume of air in the glass. To change the resonant frequency, one simply needs to add or remove liquid in the glass to change the volume of air. A more complicated example is the human vocal tract. In the human vocal tract there are many moving parts that serve to rapidly change the size and shape of the tract. In addition to changes in the length of the tract itself, complex movements of the tongue, teeth and lips cause dynamic changes in the size and shape of the vocal tract to produce the different speech sounds we hear.

Students were then shown a short video to demonstrate the complex movements of the human vocal tract.

> The following video (https://www.youtube.com/watch?v=sPp0RW3mjek) shows a real-time magnetic resonance imaging (MRI) recording of human singing. The video highlights the complex, dynamic movements in the vocal tract that produce the sounds you hear.
>
> The other primary way to change the resonant frequency of an object is to change the driving frequency at which the object vibrates. An example would be the way in which various string instruments resonate. Different strings are of different diameters and will vibrate at different frequencies. Additional frequencies can be produced by shortening the strings with the fingers.

These string vibrations provide the driving frequencies for the resonance of the instrument body. As the driving frequency changes, so does the way in which the instrument body resonates. Take for example the acoustic guitar. The body of the guitar will respond differently as the driving frequency is changed. Figure 9 shows different vibration patterns on the back of the guitar body as a function of driving frequency. The different regions (or nodes) separated by the lines in the figure are areas where the body is vibrating. The patterns of change as frequency changes reflect different "modes" of vibration, and the lines represent the boundaries between nodes where there is no vibration. The lines between nodes are called "nodal" lines.

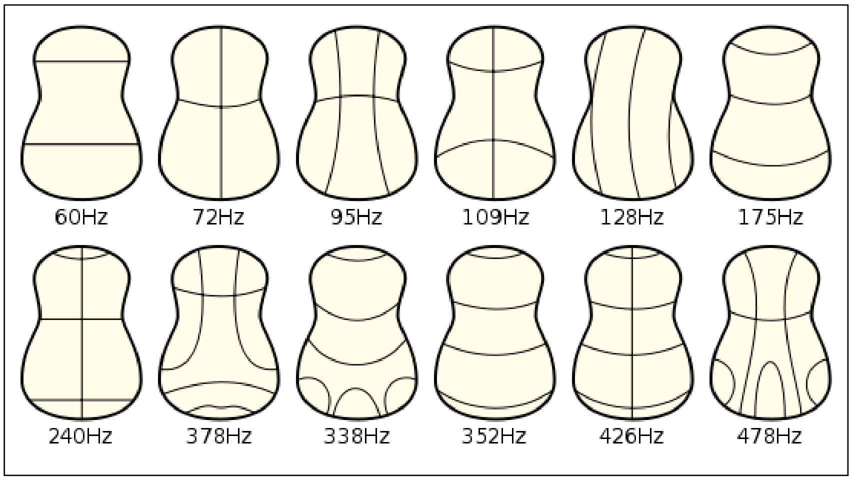

Fig. 9 Vibration patterns on the back of the guitar body as a function of driving frequency. (Image retrieved from http://en.wikipedia.org/wiki/Ernst_Chladni#mediaviewer/File:Chladni_guitar.svg.)

One way to see these nodal lines is to place a lightweight material such as salt on the vibrating body, and as the body vibrates, the material will move and eventually settle along the nodal lines to provide a visual representation of the modes of vibration. How modes of vibration change as the driving frequency changes will be demonstrated in a hands-on activity using the Chladni plate.

3.2.2 Interactive Topic Station: Chladni Plate

The Chladni plate is named for Ernst Chladni (1637–1692), who is best known for his work developing a technique for viewing the modes of vibration of a rigid surface (Chladni 2014). The purpose of the Chladni plate hands-on activity was to demonstrate the concept of resonance by using a Chladni plate built by PSB (Fig. 10) to show how the modes of vibration change with a change in the driving frequency (e.g., Rossing 1982). Instructors made changes in the driving frequency applied to a Chladni plate using a function generator and then had students draw the patterns of nodal lines they observed using a provided worksheet (Appendix, Resonance Worksheet).

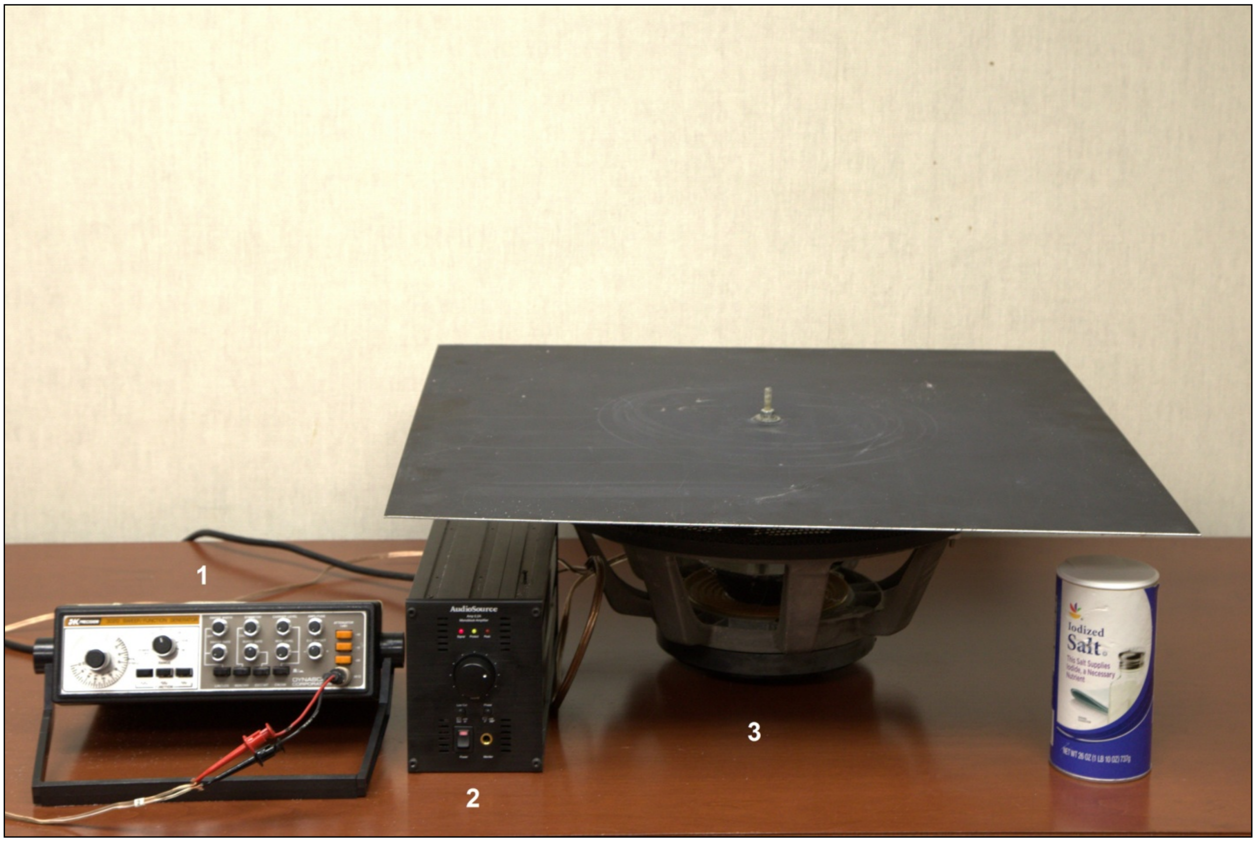

Fig. 10 ARL photo of Chladni plate station setup including 1) function generator, 2) audio amplifier, and 3) plate and loudspeaker assembly.

3.2.3 Demonstration Equipment Setup

The Chladni plate system consisted of a 16-gauge (0.0625-inch) square 24- × 24-inch piece of 6061 Aluminum sheet, a 12-inch ElectoVoice Woofer, an Audiosouce Monoblock 5.24-amp audio amplifier, and a BK Precision 3020 sweep function generator. The metal plate was affixed to the loudspeaker cone by a 1/4-inch-diameter threaded metal rod. At the loudspeaker end, the rod was bolted to a small round metal disc, which was directly affixed to the loudspeaker cone using hot glue. The rod ran through the original metal speaker grill to give added support to the sides of the rod. At the sheet metal end, the rod was affixed using washers and nuts. The loudspeaker was connected to and powered by the audio amplifier, and the driving signal was provided by the connected function generator. Fine salt crystals were spread on top of the sheet metal plate to provide the visualization of the changing modes of vibration. The equipment setup can be seen in Fig. 8.

3.2.4 Demonstration Procedure

Instructors described the setup of the Chladni plate and how it works:

> The Chladni plate is a sheet of flat metal that, when vibrated at different frequencies, will resonate with different modes of vibration. When a lightweight material such as table salt is placed on top of the plate, a visual difference can be seen in how the modes of vibration change as frequency changes. The top plate is attached to a loudspeaker cone, and it moves with the cone. The vibrations in the plate are a result of the frequency of the signal from the function generator passing through the loudspeaker. As the signal from the function generator is changed, the salt patterns on the plate change due to the change in vibration of the plate.
>
> The salt patterns that emerge as the plate vibrates at different frequencies visually demonstrate the modes of vibration. These changes can be seen as the salt crystals line up along the nodal lines. These nodal lines are areas where there is no vibration, and they form the boundaries between areas of vibration. The geometric patterns on the plate change as the driving frequency changes.

During the activity, students used a provided worksheet (Appendix, Resonance Worksheet) to draw the patterns they saw on the Chladni plate as frequency changed. Examples of the patterns are shown in Fig. 11.

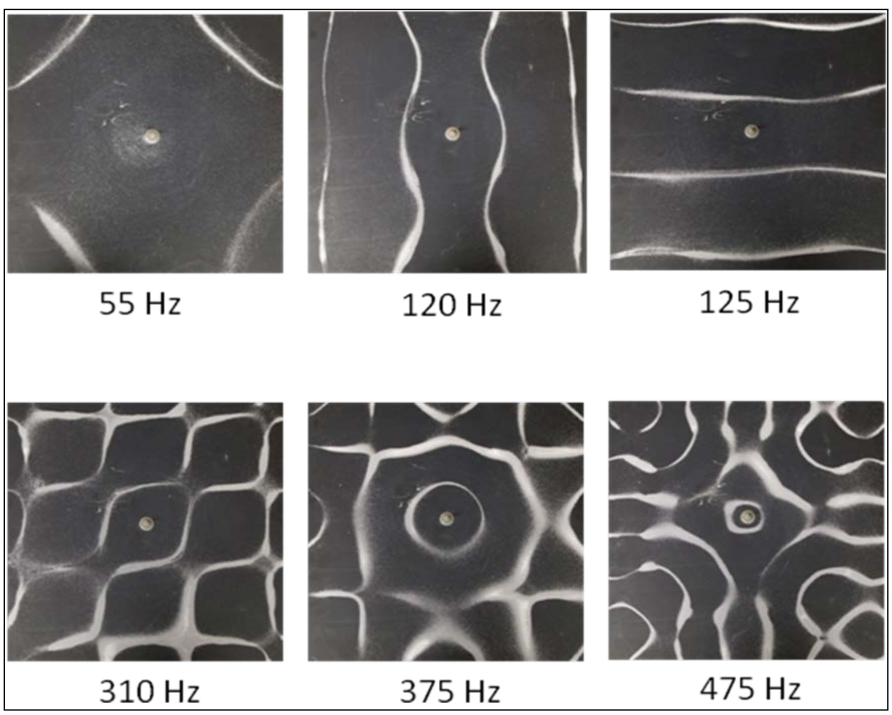

Fig. 11 ARL photo of Chladni Plate patterns

3.3 Topic 3: Bone Conduction

The topic on bone conduction introduced the concept of bone conducted hearing, explained how it works, and discussed the importance of bone conduction in everyday life, in nature, and in technology. Following the lecture, students participated at the interactive topic station for bone conduction and were able to view and try a variety of bone conduction devices.

3.3.1 Lecture Background

The following information was presented to the students by the lecturer to provide background information about the topic:

> When thinking about hearing, most people think about the air conduction pathway that was described in the first topic lecture [e.g. Gelfand 2009]. In that pathway, sound waves in the air enter the ear canal and vibrate the eardrum, and the vibrations are then transmitted via the ossicular chain to the cochlea. However, air conduction is only one pathway through which people can hear sounds. The other pathway is called bone conduction. In bone conducted hearing, sound waves in bone and soft tissue are transmitted directly to the internal ear structures, bypassing the outer ear and eardrum [Henry and Letowski 2007].
>
> Although the air conduction pathway is the dominant hearing pathway for humans most of the time, the bone conduction pathway works simultaneously and is an important part of everyday hearing. The bone conduction hearing pathway is of particular importance in several real-world experiences. For example, bone conducted hearing causes a person’s voice to sound different in their own head than it sounds to external listeners. People usually notice this effect when their voice is recorded and played back. When a person speaks, they generate sound waves in the air, and these sound waves travel to external recording devices, to listeners, and to the speaker’s own ears via air conduction. However, the speaker also generates sound waves in their own bones and soft tissues, and these vibrations travel to the speaker’s cochleae through bone conduction, influencing the speaker’s perception of their own voice. Since the speaker hears his or her own voice with both air and bone-conducted components, while an external recorder does not, the voice sounds different.
>
> Another example of when bone conduction is particularly important is when hearing while completely submerged in water. Underwater, ear canals are not in contact with external airborne sounds. However, humans and other mammals can still hear when swimming underwater, thanks to bone and tissue conduction. This can be demonstrated when submerged underwater by covering one’s ears and observing that sounds can still be heard.
>
> Bone conducted hearing is important in nature. Various animals make heavy use of bone and tissue conduction when perceiving sounds in the environment and when communicating with one another. Marine mammals such as dolphins and whales use bone and tissue conduction to hear sounds underwater [Au and Hastings 2008]. Bone conduction may also be important in long-distance communication in elephants, as sounds transmitted through the ground can be picked up

through the animals' feet and channeled via bone and tissue conduction to internal ear structures [O'Connell-Rodwell 2007]. In addition, some subterranean small mammals may have become bone conduction specialists thanks to modified middle ear structures that enhance bone conduction hearing [e.g., Mason 2003].

Bone conduction in humans has multiple practical applications and can involve technological devices. One major application of bone conduction is in the clinical diagnosis of hearing disorders. Comparing a patient's hearing performance via air conduction versus bone conduction can help pinpoint which area of the auditory pathway is not functioning properly. Similarly, bone conduction is widely used as a hearing technology for patients with conductive hearing loss, mixed hearing loss, or single-sided deafness. Bone conduction devices vibrate bones of the skull directly, thus bypassing the damage in the outer or middle ear and allowing sound to reach the inner ear. These devices can be surgically implanted or worn with a removable headband [Fig. 12].

Fig. 12 A bone-anchored hearing aid, a bone conduction device. (Image retrieved from http://commons.wikimedia.org/wiki/File:BAHA_sound_processing_device_in_place.jpg.)

Bone conduction technology can also be used in communication systems, allowing users to send and receive bone-conducted signals via headsets and radios. Using bone conduction instead of air conduction can support and improve situation awareness (by leaving ears unoccluded) in potentially dangerous environments such as those encountered by military personnel [Fig. 13], firefighters, or even joggers in traffic. Bone conduction technology can also be effectively used in high noise environments, such as military or industry, when accompanied by hearing protection devices [e.g., Pollard et al. 2014]. Outside such environments, casual-use bone conduction devices can provide novelty or convenience to users. Bone conduction cell phones do not need to be held to the ear and instead can be held anywhere against the skull. Bone conduction snorkeling headsets play music through a user's teeth, as do musical bone conduction toothbrushes.

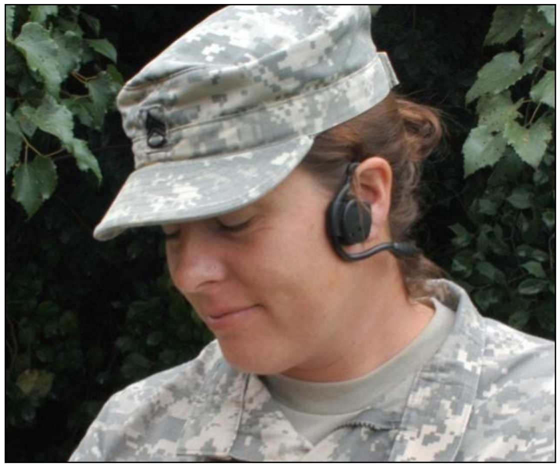

Fig. 13 ARL photo of a Soldier wearing a bone conduction communication headset. The ears are left unoccluded to maximize situation awareness.

3.3.2 Interactive Topic Station: Bone Conduction Hearing

After the lecture, students moved to a demonstration table where they could view and try on a variety of military and commercial bone conduction devices. These included commercial swimming and sport headsets, as well as military headsets that incorporated a bone microphone and bone vibrators. Students could experience bone conduction listening through the sport headset, through several unmounted bone transducers, and through tuning forks. Students experimented with different transducer locations, static force (pressure applied between the transducer and skull), and ear occlusion to experience first-hand how these factors affect bone conduction sound transmission. Students wrote down their observations on a provided worksheet (Appendix, Bone Conduction Worksheet).

3.3.3 Demonstration Equipment Setup

The demonstration layout is displayed in Fig. 14. A portable music player (fifth generation iPod Classic) was used to play the sample sounds. Music, speech samples, or both would be appropriate sound sources. Our demo employed music played on a continuous loop, and the song used was “Summer Song” by Joe Satriani. This piece was selected because it is an instrumental-only rock song with relatively constant sound levels throughout its duration.

The iPod was connected to a 4-channel Samson C-que 8-headphone amplifier, which provided additional sound amplification and finer control of sound volume. Four Radioear B70A bone vibrators were connected to the headphone amplifier so that all vibrators would play identical sound simultaneously. To avoid having the hard table surface act as a sound projector, the B70A vibrators were placed on a foam rubber pad. The bone vibrators were not attached to headbands, allowing students to freely experiment with the devices. Soft elastic headbands were available if students wished to use them. Tuning forks of different frequencies were also available for students to compare air-conducted hearing to bone-conducted hearing. Students could strike a tuning fork, listen to the sound through the air, and then touch the base of the tuning fork to their skull to listen through bone conduction. A set of 5 standard metal tuning forks was laid out on the table for students to try.

Fig. 14 ARL photo of the bone conduction station including 1) full-face respirator with Huari HRE-5673 system, 2) Samson C-que 8-headphone amplifier, 3) iPod, 4) Finis SwiMP3, 5) Goldendance Double Bone, 6) Temco HG-17, 7) Radioear B70A bone vibrators, 8) Aftershokz Sport headset, 9) Amphicom Aqua FM, and 10) tuning forks.

In addition to the loose vibrators and tuning forks, a variety of commercial and military bone conduction devices were displayed. Commercial bone conduction devices in our demo included an Amphicom Aqua FM bone conduction snorkeling system, a Finis SwiMP3 swim goggle system, and an Aftershokz Sport casual use bone conduction headset. The SwiMP3 played music through its built-in system; the Aftershokz Sport could be attached directly to the iPod for demonstration. The military headsets displayed included combined bone conduction vibrator and bone conduction microphone capability. In addition, a bone conduction communication system designed for gas masks (Huari HRE-5673) was displayed attached to a military full-face respirator (M50 Joint Service General Purpose Mask). Alcohol-based sanitary wipes were used to wipe down the equipment.

3.3.4 Demonstration Procedure

The bone conduction station was a hands-on activity wherein each student could be experiencing a different item simultaneously and could self-select which items they wanted to experience. The instructor conveyed information in an informal manner, ordered and emphasized differently depending on the interests displayed by each group of students. Thus, this section is a procedural summary of their general experiences.

Students were first introduced to the Radioear B70A bone conduction vibrators. The instructor explained that the smooth curved side of the vibrators should be placed against the skull or mandible to transmit the sound via bone to the listener's inner ears. Once the students tried this and confirmed that they could hear the bone-conducted sounds, they were encouraged to experiment with different skull locations, to try different pressure levels, and to try different numbers of vibrators used simultaneously. Students were offered soft elastic headbands if they wanted to use them to secure the vibrators to their heads. If the students did not spontaneously try key skull locations (such as the mastoid process behind the ear, the mandibular condyle in front of the ear, or the center of the forehead), then the locations were suggested. The instructor mentioned that skull location, static force, and number of vibrators are active areas of study in bone conduction research, as scientists are learning how to optimize bone conducted sound transmission and wearing convenience for different applications. After students experimented with different configurations, they were instructed to occlude their ears with their fingers or with the previously provided earplugs and compare the quality of the bone-conducted sound in both occluded and unoccluded conditions. The instructor reminded students that bone conduction can be used with ears unoccluded to permit situation awareness of the surrounding environment, and that bone conduction can be used with occluded ears (i.e., with hearing protection) when in high noise environments. Students were given time to perform the occlusion experiment and to try out different skull locations, pressures, etc. in the occluded and unoccluded condition. Students wrote their observations down on the provided worksheet (Appendix, Bone Conduction Worksheet).

Students were then introduced to the tuning forks. Students were instructed to strike the forks on the rubber soles of their shoes and to hold the stem of the fork to prevent quelling the vibrations. The instructor demonstrated placing the bottom tip of a vibrating tuning fork against the skull to hear the vibration via bone conduction. Students were then allowed to experiment with different frequencies of tuning forks, heard through the air and through bone, and with and without ear occlusion.

Finally, students were introduced to the commercial and military bone conduction headsets on display. The instructor explained the function of the commercial and military headsets. The Finis SwiMP3 goggles and Amphicom Aqua FM snorkel allow a person to listen to music or radio while swimming, and the Aftershokz Sport is intended for use while walking, jogging, or other casual activities. For the military headsets, bone conduction microphones were explained. The instructor asked students to recall the fact that speaking generates vibrations in the air and in the speaker's bones. It was then explained that a bone conduction microphone is designed to pick up the bone vibrations generated when a person speaks. Students were permitted to try on any of the headset devices (except the snorkel), and alcohol wipes were available to clean the equipment between uses. Because of time and space constraints, students did not acoustically test the military bone microphone systems but were allowed to try them on if they wished.

4. Conclusion

The objective of GEMS is to educate students with information in areas of science, engineering, mathematics, computational sciences, computation biology, biomedical sciences, chemistry, and biology that they would not normally be exposed to in school. The instructors provided students with age-appropriate lecture material and interactive activities to demonstrate topics related to research within the PSB laboratory. The 3 topics included 1) anatomy and physiology of hearing with a special focus on hearing conservation, 2) acoustic resonance, and 3) bone conduction hearing. Students were provided with handouts of the lecture material to have as a reference. In addition, PSB presenters discussed their educational backgrounds and job positions to expose students to different job opportunities and career paths. The purpose of this technical report is to document the lecture and demonstration materials that were developed for this program. These materials can be used for future outreach programs.

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Appendix. Environment for Auditory Research (EAR) Presentation

This appendix appears in its original in its original form, without editorial change.

Environment for Auditory Research (EAR)

GEMS 2014

Overview

- Hearing & Hearing Conservation
  - Activity with Portable Media Player
- Resonance
  - Chladni Plate Demonstration
- Bone Conduction
  - Activity with Bone Conduction Headsets

Hearing &
Hearing Conservation

Anatomy

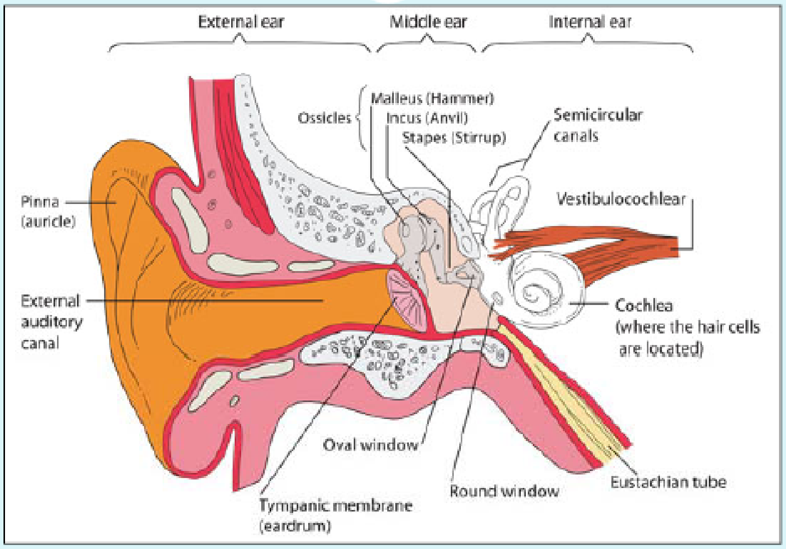
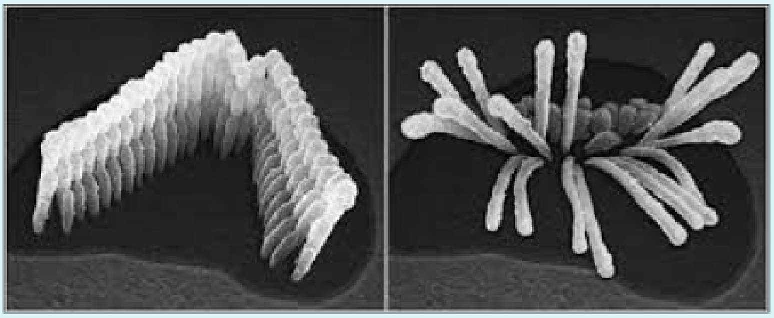


Image retrieved from: http://www.dangerousdecibels.org/education/information-center/how-we-hear/
Video retrieved from: http://www.youtube.com/watch?v=flIAxGsV1q0

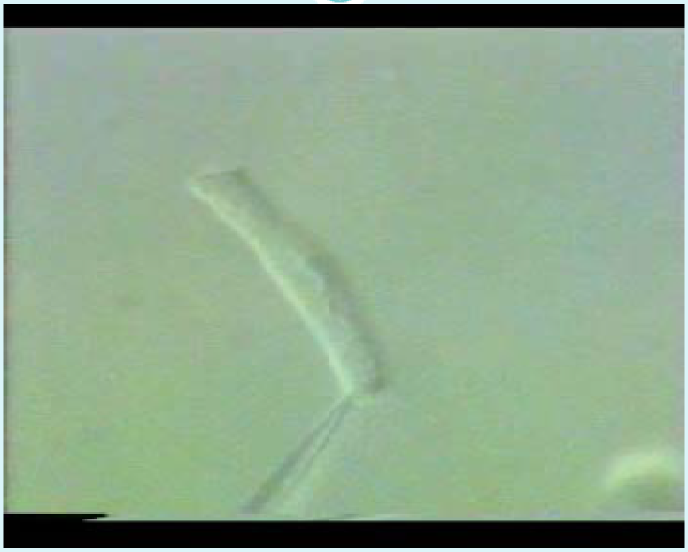
Hair Cells



Normal hair cells (left) Damaged hair cells (right)

Image retrieved from: http://www.dangerousdecibels.org/education/information-center/

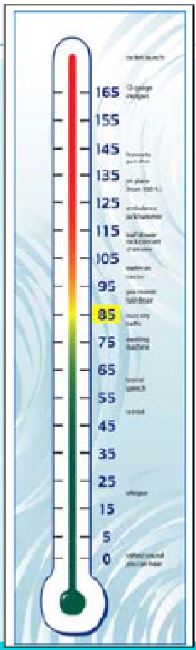
Dancing Hair Cell



Video retrieved from: http://auditoryneuroscience.com/ear/dancing_hair_cell

Hearing Conservation

Continuous dB	Permissible Exposure Time
85 dB	8 Hours
88 dB	4 hours
91 dB	2 hours
94 dB	1 hour
97 dB	30 minutes
100 dB	15 minutes
103 dB	7.5 minutes
106 dB	3.75 minutes (< 4 min)
109 dB	1.875 minutes (< 2 min)
112 dB	.9375 min (~ 1 min)
115 dB	.46875 min (~ 30 sec)



Images retrieved from: http://www.dangerousdecibels.org/education/information-center/decibel-exposure-time-guidelines/

Ways to Protect your Hearing

Images retrieved from: http://www.dangerousdecibels.org/about-us/the-solutions/

Activity: Portable Media Player

Portable Media Player Worksheet

Calibration value (CV_{offset}): ____________________

Relative Listening Level (RL): ____________________

Listening Level (LL): $LL = CV_{offset} + RL$ ____________________

Permissible Exposure time: ____________________

Resonance

Concept of Resonance

- **ALL OBJECTS HAVE NATURAL RESONANT FREQUENCY(S)**
- **RESONANT FREQUENCY CAN CHANGE BASED ON:**
  1) Changes in size and shape of the object
  2) Changes in the driving frequencies
- **RESULT IN CHANGES IN MODES OF VIBRATION**
- **EXAMPLES:**
  - Speech Articulation
  - Musical Instruments
  - Chladni Plate

REAL-TIME MRI OF SPEECH

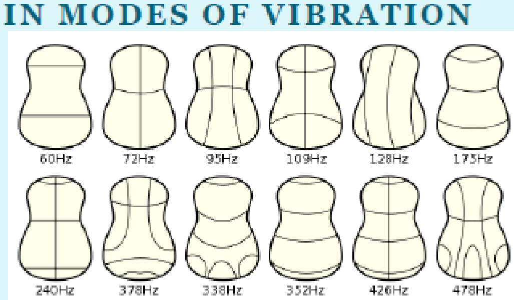


Image retrieved from: http://en.wikipedia.org/wiki/Ernst_Chladni#mediaviewer/File:Chladni_guitar.svg

Activity: Chladni Plate Demonstration

Like the guitar example, changing the driving frequency changes the modes of vibration across the plate.

Image retrieved from: http://en.wikipedia.org/wiki/Ernst_Chladni#mediaviewer/File:Chladni_guitar.svg

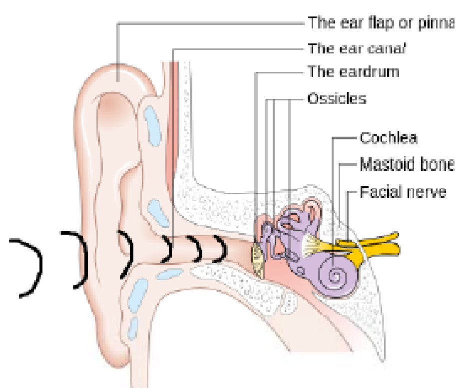
Resonance Worksheet

Draw the patterns you observe for each driving frequency.

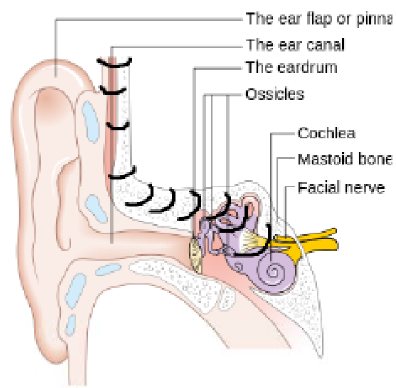
Driving Frequency ____________Hz	Driving Frequency ____________Hz	Driving Frequency ____________Hz
Driving Frequency ____________Hz	Driving Frequency ____________Hz	Driving Frequency ____________Hz

Bone Conduction

Air Conduction vs. Bone Conduction



Air Conduction Hearing

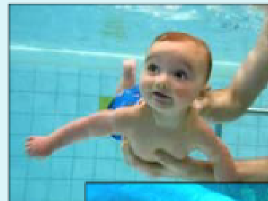


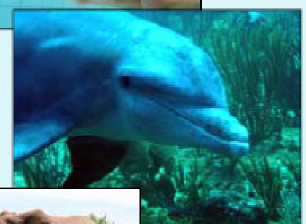
Bone Conduction Hearing

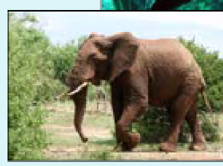
Images retrieved from:
http://commons.wikimedia.org/wiki/File:Diagram_showing_the_parts_of_the_ear_CRUK_325.svg, modified by ARL

Bone and Tissue Conduction

- Why your voice sounds different in your head than it sounds to everyone else
- How you hear underwater
- Important hearing pathway for aquatic mammals, subterranean animals, elephants
  - Water and land vibrations
- Very useful technology, broad applications







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https://www.flickr.com/photos/usoceangov/6011306163/
http://commons.wikimedia.org/wiki/File:African_Elephant_walking.JPG

Bone Conduction Uses

- Hearing assessment & hearing aids
- Noisy environments
  - Worn with hearing protection
  - Military, industry, vehicles
- Situation awareness
  - Ears open to outside sounds
  - Military, firefighters, police, joggers, casual use
- Just for fun
  - Cell phones, toothbrushes, swimming

Images retrieved from:
http://commons.wikimedia.org/wiki/File:CES_2012_-_Aftershokz_bone_conduction_headphones_%286937588341%29.jpg

Activity: Bone Conduction Demonstration

Bone Conduction Worksheet

1. What were you listening to?

music   speech   both

2. Try listening at different skull locations. What skull locations did you try? List at least three.

__________________   __________________   __________________

3. Does the sound differ among the different skull locations? Describe.

4. Listen both with your ears plugged and not plugged. How does the sound differ in these two conditions?

5. What is one application or situation where bone conduction is useful? Why is bone conduction useful for this application or situation?

List of Symbols, Abbreviations, and Acronyms

ARL	US Army Research Laboratory
GEMS	Gains in the Education of Mathematics and Science
HRED	Human Research and Engineering Directorate
KEMAR	Knowles Electronic Manikin for Acoustic Research
LL	listening level
NISOH	National Institute for Occupational Safety and Health
PC	personal computer
PSB	Perceptual Sciences Branch
RL	relative level
STEM	science, technology, engineering, and mathematics

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