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The Frequency Attenuations of Foam Ear Plugs Affected by User Error of College Students

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THE FREQUENCY ATTENUATIONS OF FOAM EAR PLUGS AFFECTED BY USER ERROR OF COLLEGE STUDENTS

by

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ABSTRACT

ALYSE JACQUELINE LEMOINE: The Frequency Attenuations of Foam Ear Plugs Affected by User Error of College Students
(Under the direction of Dr. Rebecca Lowe and Dr. Susan Loveall)

This paper examines the relationship between the attenuating ability of foam ear plugs at low and high frequencies and the effects of incorrect ear plug fitting by college students. The National Institute for Occupational Safety and Health (1998) recommends the use of a hearing protection device (HPD) such as ear muffs or ear plugs to avoid noise induced hearing loss (NIHL). However, when not inserted properly, a HPD's effectiveness can be adversely affected by user error and present as a decrease in attenuation. Attenuation is measured and presented on packaging as the noise reduction rating (NRR). A high NRR affected by user error can create a false sense of security, resulting in the frequent misuse of hearing protection. This paper explores the effect of user error in college students on foam ear plug attenuation by determining whether low or high frequencies are most perceived by the participant in audiometric testing. Testing utilized narrow band noise (NBN) and warble tones as stimuli presented in a sound field. Participants were asked to listen for the presented stimulus while wearing foam ear plugs fit by themselves as well as ear plugs fit by a trained experimenter. Results showed user error was greater in the lower frequencies than the higher frequencies. Additionally, there was no clinically significant difference between NBN trials and warble tone trials.

Keywords: user error, hearing protection devices, noise reduction rating

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LIST OF ABBREVIATIONS

ASHA……………………………….….……..American Speech and Hearing Association

CDC………………………………………………………Center for Disease Control

CSD……………………………………………Communication Sciences and Disorders

DB…………………………………………………………………………Decibels

EF……………………………………………………………….....Experimenter Fit

HPD…………………………………….……………..…..Hearing Protection Device

HZ…………………………………………………………………………….Hertz

IRB……………………………………………………..Institutional Review Board

MIRE…………………………………………………...…Microphone in Real Ear

NBN……………………………………………………...…Narrow Band Noise

NIHL……………………………………………………Noise Induced Hearing Loss

NIOSH………………………….…… National Institute for Occupational Safety and Health

NRR……………………………………………………...…..Noise Reduction Rating

REAT……………………………………………..…Real Ear Attenuation Threshold

SF……………………………………………………………………..Subject Fit

SNHL…………………………………….…………….Sensorineural Hearing Loss

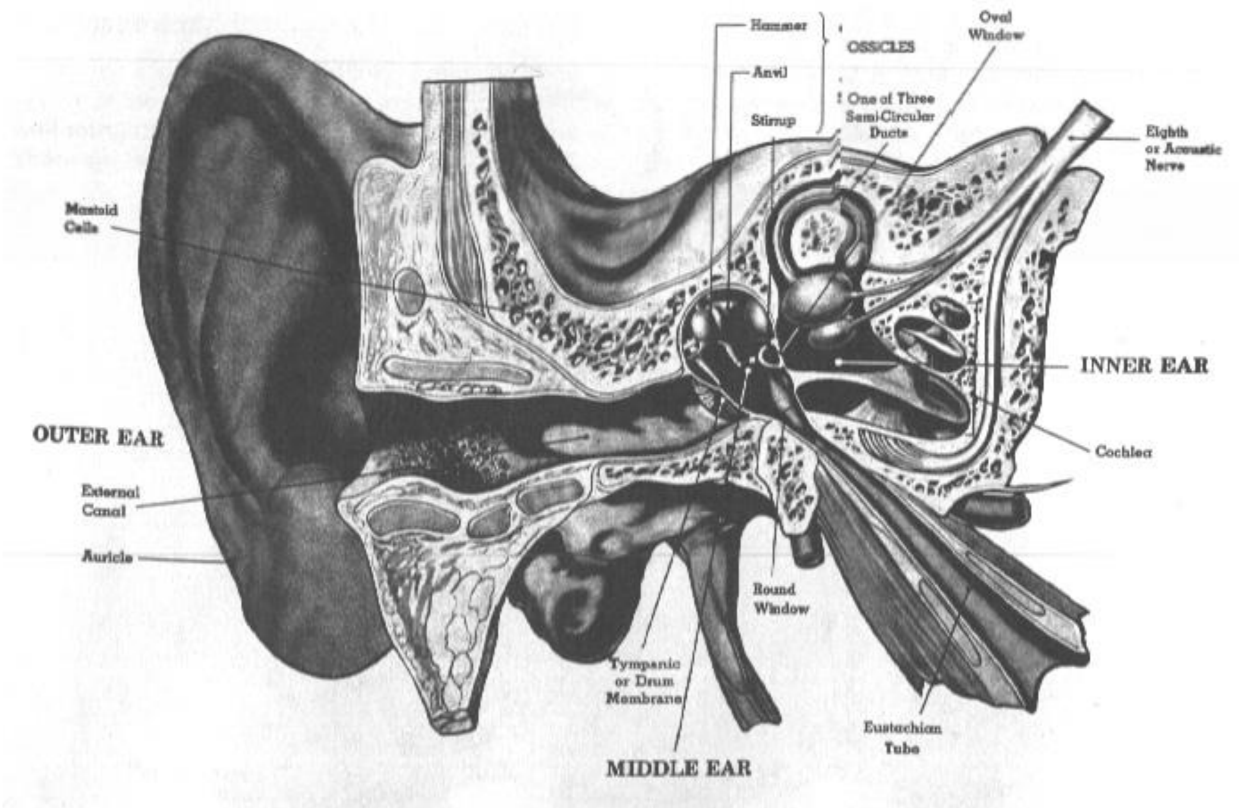
WT……………………………………………………………………Warble Tone

CHAPTER I

INTRODUCTION

The research surrounding hearing conservation is extensive. Hearing conservation includes: education on the effects of hearing loss, the awareness of the risk of excessive noise exposure, and the availability and use of hearing protection devices (HPD) (Keppler, Ingeborg, Sofie, & Bart, 2015). Noise, an ordinary and expected part of life, can be dangerous to the hearing system. The human auditory system is sensitive, and the structures are often left unprotected. Noise-induced hearing loss (NIHL) can be caused in two main ways: brief exposure to high intensity sounds called impulse noise and prolonged or repeated exposure to steady high-level sounds (Chan, Ho, & Ryan, 2016). Many individuals experience NIHL without ever realizing the danger. They can experience what is called a temporary threshold shift. A temporary threshold shift is a nonpermanent hearing loss usually associated with intense noise (Martin & Clark, 2015). This type of hearing loss can be accompanied by tinnitus, which is often described as ringing, roaring, or hissing in the ear (Martin & Clark, 2015). Over time, hearing partially or fully recovers to healthier levels. Less fortunate individuals can experience a permanent threshold shift. A permanent threshold shift is a permanent hearing loss usually associated with intense noise (Martin & Clark, 2015). This hearing loss occurs when the outer hair cells of the cochlea are damaged beyond repair, as they cannot grow back. NIHL most commonly affects both ears equally, excluding cases regarding firearms. The hearing loss often begins in the higher frequencies, and can spread to the lower frequencies over time with additional noise exposure (Alam et al., 2013). As NIHL is permanent, the preferred method of intervention is not direct treatment, but actual prevention with hearing protection devices (HPD) such as ear plugs or ear muffs.

Figure 1: Anatomy of the Ear



Suter A.H., *Hearing Conservation Manual*, 3rd Edition. Council for Accreditation in Occupational Hearing Conservation, Milwaukee,1993.

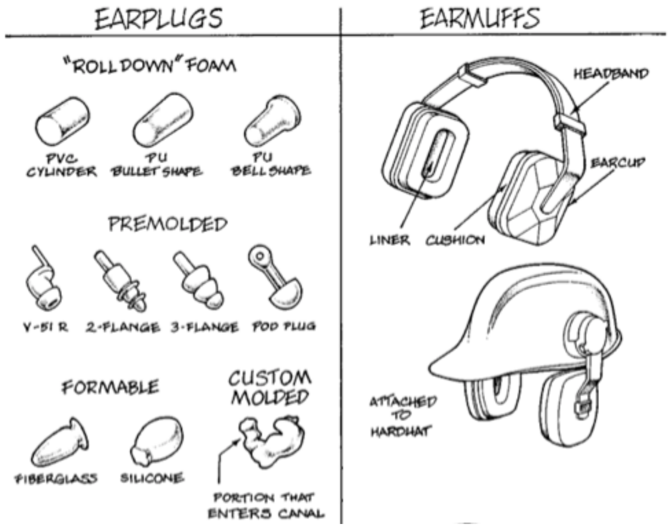
The anatomy of the auditory system can be divided into three main parts: the outer ear, the middle ear, and the inner ear (Martin & Clark, 2015). The outer ear consists of the auricle, the visible portion of the ear, and the ear canal. The auricle and ear canal act as a funnel, directing sound toward the middle ear (Center for Disease Control, 2016). The middle ear contains the ear drum and three tiny bones called ossicles. The ossicles are the malleus (hammer), incus (anvil), and stapes (stirrup). The three bones make up the ossicular chain, with the malleus attaching to the ear drum. When acoustic energy vibrates the ear drum, the acoustic energy becomes mechanical energy through the consequential movement of the ossicles (Martin & Clark, 2015). This mechanical energy is passed to the fluid-filled organ of the inner ear, the cochlea. The cochlea contains tiny hair cells which, when stimulated by the mechanical energy traveling in the fluid, send neural signals through the auditory neural system (CDC, 2016).

Sensorineural hearing loss (SNHL) is a hearing loss that results from damage to the sensory mechanism of the inner ear, the cochlea, or the neural structures beyond the cochlea (Martin & Clark, 2015). When this damage is caused by harmful noise wearing down or destroying the outer hair cells in the cochlea, the resulting damage is called noise induced hearing loss (NIHL). The outer cochlear hair cells are sensitive, and cannot regenerate once damaged. When they become too damaged by noise exposure, they can no longer properly relay stimuli to the auditory neural pathway (CDC, 2016). NIHL is a SNHL. Almost 30% of hearing loss in the adult population is caused by noise (Salmani Nodushan, Mehrparvar, Torab Jahromi, Safaei, & Mollasadeghi, 2014). Exposure to loud noise is the second most common cause of hearing loss behind presbycusis, which is loss of hearing associated with old age (Martin & Clark, 2015; Alam et al., 2013).

Sound can be defined as pressure waves from a vibrating source travelling through an elastic medium (Martin & Clark, 2015). Two main means of measuring sound are frequency and intensity. Frequency is the rate of the sound pressure waves over a given period of time (CDC, 2016). The rate is measured in Hertz (Hz), which is the number of cycles per second (Martin & Clark, 2015). Individuals perceive frequency as pitch. Frequency and pitch correlate directly, meaning low frequency sounds are low in pitch and high frequency sounds are high in pitch (Martin & Clark, 2015). Intensity is the amplitude of the sound pressure waves (CDC, 2016). The sound is measured in decibels (dB), and is perceived as loudness (Martin & Clark, 2015). The larger the number of decibels, the louder the sound. Low amplitude sounds are perceived as quiet, and high amplitude sounds are perceived as loud (Martin & Clark, 2015). Decibels are on a logarithmic scale. This scale means that the difference in sound pressure between each decibel increases as the decibel level increases (CDC, 2016). Furthermore, this logarithmic scale means that 0 dB is not a lack of sound. Zero decibels means that the selected sound is equal to the reference sound used in the equation, instead of equal to silence (Raphael, Borden, & Harris, 2008). The reference sound utilized is the average lowest level of hearing of an individual. Therefore, sounds can actually be recorded using negative decibels.

A hearing protection device is a device designed to reduce the level of sound reaching the wearer’s inner ear (Alam et al., 2013). The most basic forms of HPDs are ear plugs and ear muffs. Ear plugs can be pre-molded or moldable, and are inserted to block the ear canal (Alam et al., 2013). Moldable ear plugs can be made of materials like polymer foam or silicon putty, and form to the shape and size of the ear canal when inserted (Alam et al., 2013).

Figure 2: Basic Types of HPDs



Berger, E. H., Royster, L. H., Royster, J. D., Driscoll, D. P., & Layne, M. (2003). *The Noise Manual* (5th ed.). Fairfax, VA: AIHA Press.

Ear plugs should attenuate loud sounds, making them sound softer. When sound pressure waves reach a foam ear plug, the vibrations cannot pass as easily through the foam, as foam is a less elastic material than air. The amplitude of the sound wave decreases as it travels, and likewise so does the intensity, or loudness, of the sound. This decrease in intensity is due to the energy lost as the sound tries to move through the less elastic foam.

Attenuation is the weakening of a strength of a sound (Witt, 2016). The attenuating power of a HPD is presented on the packaging as the noise reduction rating (NRR) (Witt, 2016). NRR is a single number measurement required by law that describes the protector's noise reduction capabilities (Witt, 2016). The current range of NRRs available for purchase is 0-33 NRR (Witt, 2016). NRR is not a perfect real-world attenuation measure, but it is the most standardized method of describing attenuation capability (Witt, 2016). When calculating NRR, the initial calculations result in a reduction rating significantly higher than average attenuation across frequencies.

Experimenters properly fit the HPD on participants in a laboratory setting, so the resulting NRR may not be applicable to a real-world population. To address this discrepancy, cushions and corrections are added to the reduction rating to equal the final NRR seen on packaging (Witt, 2016). Therefore, an NRR only accurately represents how many decibels are being attenuated by a hearing protection device if the HPD has been fitted on the participant correctly. Training in HPD utilization is vital to proper and safe protection while experiencing large levels of noise exposure.

The National Institute for Occupational Safety and Health (NIOSH) (1998) recommends the use of a hearing protection device to avoid NIHL. In fact, most workers in industrial fields should receive training regarding the proper use of HPDs as part of their employment orientation (NIOSH, 1998). NIOSH (1998) published an Occupational Noise Exposure manual that states the duration an individual should be able to be in the presence of varying levels of loud sound.

Table 1:

Combinations of noise exposure levels and durations that no worker exposure shall equal or exceed

Exposure level, *L* (dBA)	Duration, *T* Hours	Minutes	Seconds	Exposure level, *L* (dBA)	Duration, *T* Hours	Minutes	Seconds
80	25	24	–	106	–	3	45
81	20	10	–	107	–	2	59
82	16	–	–	108	–	2	22
83	12	42	–	109	–	1	53
84	10	5	–	110	–	1	29
85	8	–	–	111	–	1	11
86	6	21	–	112	–	–	56
87	5	2	–	113	–	–	45
88	4	–	–	114	–	–	35
89	3	10	–	115	–	–	28
90	2	31	–	116	–	–	22
91	2	–	–	117	–	–	18
92	1	35	–	118	–	–	14
93	1	16	–	119	–	–	11
94	1	–	–	120	–	–	9
95	–	47	37	121	–	–	7
96	–	37	48	122	–	–	6
97	–	30	–	123	–	–	4
98	–	23	49	124	–	–	3
99	–	18	59	125	–	–	3
100	–	15	–	126	–	–	2
101	–	11	54	127	–	–	1
102	–	9	27	128	–	–	1
103	–	7	30	129	–	–	1
104	–	5	57	130–140	–	–	<1
105	–	4	43	–	–	–	–

National Institute for Occupational Safety and Health. *Occupational noise exposure*. (1998). Cincinnati, OH: U.S. Dept. of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention.

According to NIOSH (1998), as a basic rule an individual should not be exposed to noise louder than 140 dB, regardless if the noise is continuous or intermittent. For lesser sounds a scale can be utilized. Fundamentally, the louder a given noise is, the less time a person can safely be exposed. An 85dB noise can be withstood for eight hours, but an 88 dB noise can only be withstood for four hours. Additionally, a 91dB sound can only be heard for two hours, and a 94dB sound can be heard for one hour. Because decibels are logarithmic units, the decibel to time ratio is not directly inversely related. To put this information in perspective, a loud rock concert would average at 115 dB (Martin & Clark, 2015). By NIOSH's (1998) scale, an individual could only safely listen to the event for 28 seconds. Additionally, a person could only listen to the average iPhone on full volume of 110dB for one minute and 29 seconds.

When testing hearing protection devices, one method of audiometric testing is sound field audiometry. Sound field audiometry utilizes air conduction, meaning that the sound travels through the outer ear, the middle ear, and the inner ear to be heard (Martin & Clark, 2015). Instead of being fit with insert headphones or supra-aural headphones, the client is placed equidistant between two speakers in opposite corners of a sound booth. The purpose of audiometry is to measure hearing sensitivity (CDC, 2016). The goal is to find the client's hearing threshold, which is the level at which the subject can detect the sound 50% of the times that the sound is presented (CDC, 2016). Audiometry is conducted using a machine called an audiometer. An audiometer can produce sound stimuli at across multiple frequencies through different transducers such as supra-aural headphones, insert headphones, bone oscillators, and speakers. Hearing thresholds are found at select frequencies ranging from 250 Hz to 8000 Hz. Speakers in sound field are ideal for testing hearing protection devices. Wearing headphones on top of ear plugs can affect the attenuation measurements gathered during audiometry, as they can put pressure on the ear plug to further the insertion into the ear canal (Tufts, Palmer, & Marshall, 2012).

The ideal method for finding the attenuation capability of HPDs in sound field is the real ear attenuation threshold (REAT) method. This method, which is described in Canetto (2009), involves the collection of a baseline hearing threshold and the hearing threshold of the participant while they are wearing the selected HPD. The baseline threshold acts as a condition for comparison. These values are compared to calculate a hearing protector's real ear attenuation. Additionally, two common sound stimuli used in audiometry are narrow band noise and warble tone. Narrow band noise is a restricted, band of frequencies surrounding a particular chosen frequency (Martin & Clark, 2015). The stimuli is often used for masking and can be described as calibrated white noise. Warble tone is a modulated pure tone (Martin & Clark, 2015). A puretone is a tone of a single frequency, so a modulated pure tone is a tone that varies from the chosen frequency by a specifically measured amount. For example, a 1000 Hz tone warbled at 5% would vary from 950 Hz to 1050 Hz (Martin & Clark, 2015). Both sound stimuli are available at any given frequency on an audiometer.

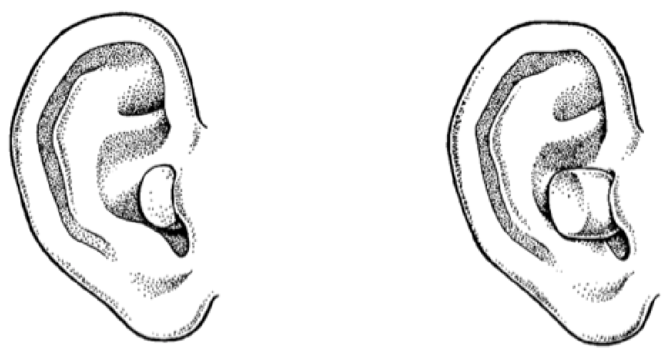
In assessing proper attenuation of HPD, both outer and middle ear must be clear. Two tests commonly used will assess those parts of the ear. The first test of the auditory system to determine an individual's auditory health is otoscopy. Otoscopy is a visual examination of the outer ear (CDC, 2016). The outer ear includes the auricle and the ear canal. The main purpose of otoscopy is to identify any abnormalities that may require an alternate testing procedure, and to identify any conditions requiring a medical referral (CDC, 2016). The equipment utilized in otoscopy is an otoscope. Otoscopic examination ensures that there are no visible issues that may hinder further audiometric testing, and is typically the first test administered in a battery of tests to assess the auditory system.

Additional testing for audiometric health is tympanometry. Tympanometry is an objective test of middle ear function (CDC, 2016). The main purpose of tympanometry is to test the mobility of the tympanic membrane (CDC, 2016). The tympanic membrane allows for inference on the condition of the rest of the middle ear system. The equipment utilized in the procedure is a tympanometer. Based on the ear drum's flexibility, a graph called a tympanogram is drawn and the status of the middle ear system can be inferred (Martin & Clark, 2015). The tympanometric assessment of the middle ear status is typically the next test in a basic hearing evaluation. For proper assessment of the accurate attenuation of an HPD in sound field both otoscopy and tympanometry should yield normal results.

The results of audiometric testing are recorded and plotted on graphs called audiograms. Audiograms are a visual representation audiometric findings that show hearing thresholds as a function of frequency (Martin & Clark, 2015). Audiograms have an x-axis of frequency typically ranging from 125 Hz to 8000 Hz. The audiogram's y-axis is intensity ranging from -10 dB to about 110 dB. Hearing thresholds are considered in the normal hearing range for adults if they fall between -10 dB and 15 dB (Martin & Clark, 2015). Audiometric screening is a way of ensuring normal hearing function without finding the hearing threshold. If the client responds to 25 dBHL then they can hear at the bottom of the normal adult hearing range. For accurate assessment of HPD attenuation a person should be able to detect frequencies tested at 25 dBHL. Therefore, in accurately evaluating attenuation approximations, otoscopy and tympanometry should yield normal results and a person should have normal hearing as evidenced by passing a 25 dBHL screening.

When testing HPDs two conditions in fitting the HPDs exist: subject fit and experimenter fit. If the participant fits the hearing protector themselves, the HPD is subject-fit (SF). If the researcher fits the participant with the hearing protector, the HPD is experimenter-fit (EF) (Canetto, 2009). Comparing these two conditions with each other allows for the calculation of user error. User error is the result of erroneous fitting or utilization of a hearing protection device by the user, which causes a decrease in attenuation.

Figure 3: Proper Foam Ear Plug Insertion



— Demonstration of a proper (left) and improper (right) fit of a foam earplug.

Berger, E. H., Royster, L. H., Royster, J. D., Driscoll, D. P., & Layne, M. (2003). *The Noise Manual* (5th ed.). Fairfax, VA: AIHA Press.

User error can be calculated by subtracting the SF threshold from the EF threshold. This comparison shows a more accurate difference in attenuation for each participant rather than against the NRR on the packaging, as some participants may receive better attenuation from a standard sized ear plug than others due to factors such as ear canal size (Salmani Nodushan et al., 2014).

CHAPTER II

LITERATURE REVIEW

The research surrounding hearing conservation is extensive. Many studies have outlined the dangers of overexposure to loud noise and how to protect hearing health. For example, Singh, Bhardwaj, and Kumar (2012) found that even when following proper safety procedures, factory workers can still be overexposed to noise, which can lead to NIHL. The National Institute for Occupational Safety and Health (1998) recommends the use of a hearing protection device (HPD) such as ear muffs or ear plugs to avoid NIHL, and they offer guides to better understand what noise levels are considered safe. However, most of the research regarding this NIHL prevention, such as that by Fonseca, Marques, Panegalli, de Oliveira Gonçalves, and Souza (2016), focuses on workers in industrial settings: factories, mills, use of firearms, etc. Most workers in such fields should receive training regarding the proper use of HPDs, as well as the chosen HPDs themselves, as part of their employment orientation when they begin their job (NIOSH, 1998). Other various populations can experience equal risk of dangerous noise exposure without the equal education and protection of training in HPD use. Young adults are often exposed to dangerous noise without the proper protection (Keppler et al., 2015). Those individuals who do utilize HPDs may not be using them correctly. When inserted improperly, a hearing protector's effectiveness can be adversely affected by user error, regardless of the proposed attenuation on the HPD packaging.

Attenuation is presented on HPD packaging as the noise reduction rating (NRR) (Witt, 2016). Currently, the U.S. market offers HPDs with an NRR range of 0 to 33 decibels (Witt, 2016). However, even a good NRR is ineffective if the HPD is used incorrectly or without training (Salmani Nodoushan, Mehrparvar, Torab Jahromi, Safaei, & Mollasadeghi 2014). When donning hearing protection incorrectly, user error can be dangerous. Wearing hearing protection devices with a high NRR can create a false sense of security. This false sense of protection can result in frequent misuse of hearing protection, which can lead to NIHL. In fact, a properly fitted HPD with a lower NRR on the packaging can attenuate better than an improperly fitted HPD with a higher NRR on the packaging, as seen in a study conducted by Salmani Nodoushan et al (2014). One group received training in the use of HPDs and were given ear plugs with a NRR of 25, while another group did not receive training and were given ear plugs with a NRR of 30. The trained group with NRR 25 ear plugs received better attenuation than the untrained group with NRR 30 ear plugs. Salmani et al (2014) utilized the REAT method, and compared baseline hearing thresholds to attenuated thresholds. If user error affects the attenuation of frequencies often present in noisy environments, then the user's inner ear could still be vulnerable to damage at that frequency. Schmuziger, Fostiropoulos, and Probst (2006) explain that such damage often begins as a temporary threshold shift, which is a decrease in hearing sensitivity that typically returns to former levels within a few hours and characterized by tinnitus and decreased hearing sensitivity. However, the damage can be a permanent threshold shift. This hearing loss is due to wearing down of cochlear hair cells from the intense noise levels.

The danger of noise induced hearing loss is not limited to industrial workers. Dangerous noise exposure is prevalent across numerous environments. Young adults in particular expose themselves to loud noise in venues such as bars, nightclubs, and concerts, as well as with the use of personal music players (Keppler et al., 2015). Keppler et al. (2015) indicates that individuals who have personally experienced the symptoms of noise exposure engage in more hearing protective behavior. A study on young adults in Flanders, Belgium showed that 7% of the young adults already have NIHL, 73.5-85.9% have experienced temporary tinnitus, and 6.6-18.3% experience chronic tinnitus due to noise exposure (Keppler et al., 2015). Additionally, up to 72% of young adults never wear HPDs (Keppler et al., 2015). Keppler et al. (2015) postulated that the uncomfortable feeling of wearing them, annoyance in wearing them, the perceived pressure on the ears, and the self-perception of communication difficulties may all be factors in these individuals not wearing HPDs (Keppler et al., 2015). Without the proper use of HPDs, NIHL poses a considerable threat to a young adult's auditory system due to their extensive noise exposure. Many of these people are not in a line of work that offers proper training in HPD use, which leaves them vulnerable to NIHL.

The most effective form of HPD training is face-to-face training, which means that the instructions provided on the packaging may not be sufficient for proper hearing protection (Murphy, Stephenson, Byrne, Witt, & Duran, 1998). Murphy et al. (1998) showed that face-to-face training in HPD use was shown to be the most effective training method, followed by video instruction, and then HPD packaging instructions. These findings were consistent across the four types of pre-molded foam ear plugs used in testing. Each type of ear plug had two participant groups assigned to utilize them.

Additionally, the identification of the severity of the risk of NIHL will depend on the environment in which the hearing protection device will be utilized. Prevalent frequencies found in any given environment may not be attenuated properly due to user error in poor HPD fitting. Researching which frequency attenuations are most affected by user error will help locate which populations of hearing protection device users are most at risk for NIHL without proper training.

One common method of measuring a hearing protection device's effectiveness is the real ear attenuation at threshold (REAT) method, which is described in Canetto (2009). REAT is considered the gold standard test for measurement of threshold in an industrial environment (Salmani Nodoushan et al., 2014). This method utilizes the difference in hearing thresholds between two ears in two situations, with and without ear plugs, to measure ear plug efficacy (Salmani Nodoushan et al., 2014). Participants are first tested for the octave bands of sound in the sound field without ear plugs to gain a baseline hearing threshold. Then, ear plugs are inserted and the participants are tested in sound field again on the same octave bands. The baseline value and the protected value are compared to see attenuation capability at each frequency. This method is preferred over its' counterpart, microphone in real ear (MIRE) method due to the variability of microphone placement in the ear canal that can skew results (Alam et al., 2013). REAT also is more accurate because it can account for sound that reached the cochlea via bone conduction, because the responses are self-reported. MIRE only records the sound that makes it past the HPD, not what is perceived by the participant.

A key concept to note when reading prior research is the manner of fitting the participant with their hearing protector prior to testing. Studies with experimenter-fit

HPDs have higher attenuation values than subject-fit HPDs, due to the correct and consistent fitting of the protector by a single trained experimenter (Murphy et. al 1998). The variation is compounded by the fact that NRRs are acquired with EF ear plugs in a factory setting, even if cushion and corrections are built in (Witt, 2016). Comparison of REAT measurements from both subject-fit trials and experimenter fit trials within the same study with the same participants could isolate the difference in attenuation and more accurately attribute the discrepancy to user error. Additionally, many previous studies pulled participants from populations with access to training. Previous training could cause the results to be skewed by their previous experience. Studies with commonly untrained populations may better represent the user majority (Keppler, Ingeborg, Sofie, & Bart, 2015). The HPD chosen for the study described in this paper was a foam ear plug with an NRR of 32. Use of a foam ear plug with a high NRR could offer room for noticeable contrast between the subject-fit and experimenter-fit ear plug attenuation values.

Previous studies conducted testing utilizing two different, common sound stimuli: narrow band noise (NBN) and warble tone. NBN was utilized as one of the stimuli in the sound field testing, as it was utilized in past related studies (Salmani Nodushan et al., 2014). The warble tone was chosen as the second sound stimulus. Alam, Jalvi, Suryanarayan, Gurnani, and Barot (2013) included both warble tone and NBN as stimuli in their study regarding different hearing protection devices and their individual attenuations. Their intention was to see if a notable difference in the ability to attenuate the different sound stimuli across different hearing protection devices occurs. Alam et al. (2013) found that while speech noise and white noise had better attenuation at the select tested frequencies, the difference between the mean attenuation of NBN and warble tone was no larger than 3dB at any given frequency.

Extended exposure to continuous noise can damage the outer hair cells of the cochlea. That is why NIOSH (1998) regulates the amount of time a worker can be exposed to any given decibel level. The outer hair cells of the cochlea relay stimuli for high frequency sounds, so when they are damaged, the ability to hear higher frequencies is lost. Continuous exposure slowly wears down the outer hair cells in the cochlea over time, as even low frequency noise must bypass the outer hair cells to reach the inner hair cells receptive to low frequencies. The outer cochlear hair cells cannot grow back, so severe damage can be permanent. When the hair cells become too damaged by noise exposure, they can no longer properly relay stimuli to the auditory neural pathway (CDC, 2016). A Swedish study covered in Lie et al.'s (2016) systematic review showed that only 8-28% of the "blue-collar workers" in their study, workers in the automotive industry, shipyards, and quarries, had normal hearing in comparison to 70% with normal hearing among office workers. A study of Egyptian metal workers from the same review showed their NIHL occurring in the higher frequencies (Lie et al., 2016). Results from various studies in the systematic review can be interpreted to show NIHL from continuous noise exposure is slower and less severe to NIHL from impact noise.

Impact noise has been found to be more damaging than extended exposure to loud noise (Lie et al., 2016). By nature, impact noise is high in intensity, so the harsh mechanical energy traveling through the fluid of the cochlea can severely damage the cochlear hair cells (Clifford & Rogers, 2017)). Additionally, impact noise is often high in frequency, which means the damaging energy first hits the receptive outer hair cells

(Martin & Clark, 2015; Clifford & Rogers, 2017). The high energy levels of the sound means the length and frequency of exposure needed to cause damage is much less than continuous exposure. Lie et al.'s (2016) review contained a study of artillery recruits exposed to impact noise such as gunfire and explosions showing 17% of the recruits had a hearing loss greater than 15 dB in at least one frequency. An additional study in the review compared Canadian smelter workers from different departments of the same factory (Lie et al., 2016). Lie et al. (2016) showed the prevalence of hearing loss was greatest in areas of impulse noise and lowest in areas of continuous noise.

This current study focuses on whether high frequency attenuations or low frequency attenuations will be more affected by user error of college students utilizing foam ear plugs. Additionally, the study investigates whether the attenuation of the foam ear plugs will be similarly affected by the use of narrow band noise or warble tone as testing stimuli. Based on the information presented in Chapters I and II, the collected research pertained to the following research questions:

Research question #1: The foam ear plugs' lower frequency attenuations will be affected by user error differently than the higher frequency attenuations.

Research question #2: The foam ear plugs' frequency attenuations of the two chosen stimuli, narrow band noise and warble tones, will differ.

CHAPTER III

METHODS

Participants

The participants for this study were 38 undergraduate students, 15 males and 23females, at the University of Mississippi ages 18 to 24 years (M = 20.97, SD = 1.37). Eligibility criteria for a student to participate in the study included clear outer ear and normal middle ear function and normal hearing as determined by the American Speech-Language-Hearing Association (ASHA) screening protocol. One male was excluded due to unilateral NIHL.

- *Age:*
  - 1 Student, age 18 years-0 months to 18 years-11 months
  - 5 Students age 19 years-0 months to 19 years-11 months
  - 7 Students age 20 years-0 months to 20 years-11 months
  - 12 Students age 21 years-0 months to 21 years-11 months
  - 8 Students age 22 years-0 months to 22 years-11 months
  - 4 Students age 23 years-0 months to 23 years-11 months
  - 1 Students age 24 years-0 months to 24 years-11 months
- *Audiologic criteria:* clear outer and middle ear with included healthily functioning ear drum and hearing within normal range at 1000Hz, 2000Hz, and 4000Hz.

Recruitment

Participants responded to an email (see Appendix A) containing the generic purpose of the research study and an incentive of entry into a raffle for one of three $15 Starbucks gift cards or extra credit in a pre-determined class. Deception was utilized in describing the purpose of the study in the email so as not to affect how participants would react, this principle is known as the Hawthorne effect (Chiesa & Hobbs, 2008). The Hawthorne effect occurs when participants alter their behavior due to awareness of being watched or assessed. Knowledge of the purpose of this study might have influenced participants to insert the earplugs differently than how they would in a real-world situation. Participants were aware that multiple hearing evaluations would take place regarding ear plugs but not that their performance would be measured against an experimenter.

Equipment

Prior to audiometric testing, eligibility was established with three screening tests: otoscopy, tympanometry, and a hearing screening at 25dB at 1000Hz, 2000Hz, and 4000Hz. Otoscopy consisted of checking the ear canal with the help of an otoscope (Welch Allyn Otoscope, Welch Allyn Inc., Skaneateles Falls, New York) in order to ensure a clear ear canal and an absence of abnormalities in the outer ear (CDC, 2016). Tympanometry utilized a tympanometer (MT10, Interacoustics A/S, Eden Prairie, Minnesota) to objectively test how well the ear drum worked by assessing its mobility (CDC, 2016). Pure-tone audiometric testing was performed utilizing a two-channel clinical audiometer (GSI Audiostar Pro, Grasen-Stadler Inc, Eden Prairie, Minnesota) with sound field in a sound booth (Controlled Acoustical Environments, Industrial Acoustics Company, New York, New York) to ensure normal hearing levels.

Risks

The following appropriate measures were taken to avoid all risks associated with this research. Throughout all testing, a strict adherence to Centers for Disease Control and Prevention (CDC) infection protocols was followed (CDC, 2007). During otoscopy, the proper procedure of bracing, as outlined in the American Speech-Language-Hearing Association guidelines for audiologic screening (ASHA, 1997), was used to ensure that the otoscope tip did not go too far into the subject's ear canal. After otoscopy, otoscopy tips were discarded. During tympanometry, tympanometry tips were disinfected with CIDEXPlus according to disease control protocols set by CDC (CDC, 2007). Audiometry was conducted following ASHA standard operating procedure ensuring the safety of the subjects during testing (ASHA, 2005). The foam ear plugs utilized were The Ear Buddy, which had a NRR of 32.

Analysis

During testing data was recorded on a data collection sheet (see Appendix B). The top of the data collection sheet recorded otoscopic and tympanic results, as well as the results of the hearing screening. Additionally, the sheet recorded the participants hearing threshold at six different frequencies in three different conditions utilizing two different sound stimuli. Thresholds were recorded at 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz using narrow band noise and warble tone. These measures were recorded in three conditions: baseline threshold with no hearing protection inserted, threshold of self-fit ear plugs, and threshold of experimenter-fit ear plugs. The differences between thresholds were calculated across conditions, frequencies, and stimuli on the bottom half of the data collection sheet. These calculations included baseline vs. SF thresholds, baseline vs. EF thresholds, and SF vs. EF thresholds (user error). After audiometric testing was complete, participants filled out a 13 question questionnaire (see Appendix C) regarding their experiences in the study, as well as their history with hearing protection in the past. Comparisons in thresholds were made between low frequencies and high frequencies, as well as between NBN and warble tone. The low frequency average was calculated using the thresholds of 250 Hz, 500 Hz, and 1000 Hz. The high frequency average was calculated using the thresholds of 2000 Hz, 4000 Hz, and 8000Hz.

Questionnaire

The questionnaire was made up of 13 questions: 4 demographic and background questions, 4 questions regarding frequency of HPD use and type of training, 3 questions regarding differences between SF and EF ear plugs, and 2 questions about their perspective on the effect of training as well as their own training.

IRB Approval

Approval to conduct research with human participants utilizing deception (IRB:17-093) was successfully granted by the Institutional Review Board (IRB) at the University of Mississippi before any participants were tested (see Appendix D). Additionally, a copy of the IRB approved consent form was provided to each participant at the time of consent (see Appendix E). Participants were debriefed following the completion of the study and signed a re-consent form (Appendix F) assenting to the use of their data after revelation of deception.

CHAPTER IV

RESULTS

Initially, the participants were required to meet the three criteria of (1) normal otoscopic results, (2) normal tympanometric results, and (3) pass a hearing screening before they could continue on to extensive sound field testing. During this eligibility testing, participants were asked if they experienced any recent pain or pressure in their ears, as well as if they experienced tinnitus before the process began. The participants' outer ears were examined with an otoscope and their middle ear function tested with a tympanometer to establish exclusion criteria. No participants were excluded due to abnormal otoscopy or tympanometry. After the initial tests, the participants were given a hearing screening at 25dB at 1,000Hz, 2,000Hz, and 4,000Hz utilizing supra-aural headphones. Of the 39 participants, one did not meet these requirements due to NIHL in his right ear which was caught in the screening.

Of the 38 eligible participants (aged 18-24), 39.5% were male and 60.5% were female. Each participant was asked to meet at a scheduled time slot at the University Speech and Hearing Clinic, which acted as the testing site. All research participants signed an IRB approved consent form before they could participate in the research, as well as a re-consent form at the end of testing due to deception of purpose. Participants were individually tested utilizing sound field audiometry. Participants were led to the sound booth and instructions for baseline hearing thresholds were administered. Results were found using narrow band noise (NBN) and warble tone (WT), and recorded using the data collection sheet (Appendix C). The participant was then provided with Ear Buddy foam ear plugs, NRR 32, and instructed to insert them as they normally would. The audiometric procedures were repeated with narrow band and warble tone. At the conclusion of this step, the participants removed the ear plugs and the researcher inserted a new pair into their ears utilizing the ASHA approved procedure.

The first hypothesis considered was: *The foam ear plugs' lower frequency attenuations will be affected by user error differently than the higher frequency attenuations.*

The participants were tested at six frequencies ranging from 250-8000Hz in sound field. For the purpose of this research, user error was defined as the threshold obtained by the experimenter-fit ear plugs minus the threshold obtained by the self-fit ear plugs. Additionally, 250Hz, 500Hz, and 1000Hz were considered low frequencies, and 2000Hz, 4000Hz, and 8000Hz were considered high frequencies. User error was calculated at each frequency, then averaged together according to high or low to attain a mean user error for both low frequencies and high frequencies.

The results showed that user error was greater in the lower frequencies. Mean low frequency user error was reported at 23.77dB *(11.34)* for NBN and 25.75dB *(12.87)* for WT. Contrastingly, mean high frequency user error was reported at 15.76dB *(10.65)* for NBN and 15.31 *(10.38)* for WT (Table 2). That is, the amount of error, was greater in the lower frequencies. As a result, data supported *Research Question #1*, which indicated that there would be a difference in how user error affected the low and high frequencies.

Table 2: Means & Standard Deviations of Attenuation

	Experimenter Fit Mean (*SD*)	**Self Fit** Mean (*SD*)	**User Error** Mean (*SD*)
Narrow Band Low	38.29 (*6.24*)	14.52 (*10.36*)	23.77 (*11.34*)
Narrow Band High	42.02 (*3.25*)	26.25 (*10.31*)	15.76 (*10.65*)
Warble Tone Low	38.64 (*6.74*)	12.89 (*10.92*)	25.75 (*12.87*)
Warble Tone High	41.58 (*3.49*)	26.27 (*10.17*)	15.31 (*10.38*)

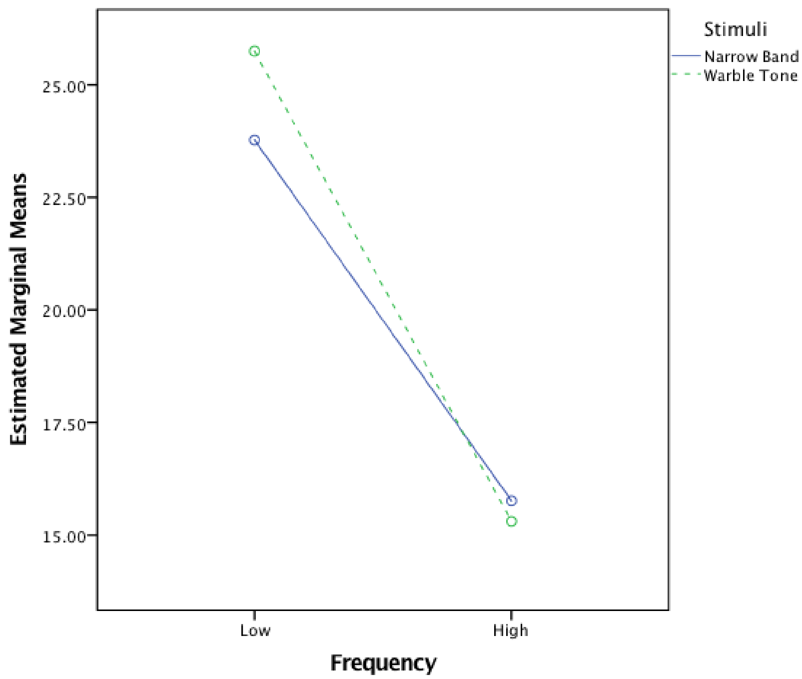
The second hypothesis considered was: *The foam ear plug's frequency attenuations of the two chosen stimuli, narrow band noise and warble tones, will differ.*

The participants were tested in sound field at the six frequencies utilizing two different stimuli, NBN and WT. The two frequencies were used in baseline, self-fit ear plug testing, and experimenter-fit ear plug testing. User error found in NBN testing was compared to user error found in WT testing.

The results indicated that the difference in user error between narrow band noise and warble tone was not clinically or statistically significant. The difference between the mean NBN low frequency and the mean WT low frequency was 1.98dB (with 23.77dB *(11.34)* for NBN and 25.75dB *(12.87)* for WT). The difference between the mean NBN high frequency and the mean WT high frequency was 0.45dB (with 15.76dB *(10.65)* for NBN and 15.31 *(10.38)* for WT). This difference was not clinically significant, as threshold testing utilizes 5dB increments. Statistically, p=.13 and therefore is >.05, is therefore, not significant. As a result, the data did not support *Research Question #2,* which indicated that there would be a difference in how user error was affected by the two sound stimuli.

A two-way repeated measures ANOVA was conducted to compare user error scores on frequency (high vs. low) and stimuli (NBN vs. WT). Means and standard deviations are presented in Table 2. Results indicated a significant interaction between frequency and stimuli, Wilks' Lambda = .77, F (1, 37) = 10.97, p = .002, partial eta squared = .23. There were differences between stimuli in low frequencies, but not high frequencies. See Figure 4.

Figure 4: Significant Interaction between Frequency and Stimuli



A significant main effect of frequency existed, with user error greater in lower frequencies than higher frequencies, F (1, 37) = 97.11, p < .05, partial eta squared = .72. Follow-up paired sample t-tests revealed a statistically significant difference between high and low frequencies for both NBN, t (37) = 9.64, p < .001, and WT, t (37) = 9.05, p < .001.

No main effect of stimuli existed, p = .13. Follow-up paired sample *t*-tests revealed a statistically significant difference in user error between NBN and WT in low frequencies, t (37) = 3.24, p = .003, but not in high frequencies, p = .46.

Table 3: Correlations between User Error and HPD Use

Correlations

		Low T2–T1 (NB) Avg	High T2–T1 (NB) Avg	Low T2–T1 (WT) Avg	High T2–T1 (WT) Avg	lastused	frequencyused
Low T2–T1 (NB) Avg	Pearson Correlation	1	.893**	.960**	.858**	.175	–.193
	Sig. (2–tailed)		.000	.000	.000	.293	.247
	N	38	38	38	38	38	38
High T2–T1 (NB) Avg	Pearson Correlation	.893**	1	.835**	.937**	.283	–.255
	Sig. (2–tailed)	.000		.000	.000	.085	.123
	N	38	38	38	38	38	38
Low T2–T1 (WT) Avg	Pearson Correlation	.960**	.835**	1	.834**	.060	–.125
	Sig. (2–tailed)	.000	.000		.000	.722	.453
	N	38	38	38	38	38	38
High T2–T1 (WT) Avg	Pearson Correlation	.858**	.937**	.834**	1	.274	–.250
	Sig. (2–tailed)	.000	.000	.000		.097	.131
	N	38	38	38	38	38	38
lastused	Pearson Correlation	.175	.283	.060	.274	1	–.840**
	Sig. (2–tailed)	.293	.085	.722	.097		.000
	N	38	38	38	38	38	38
frequencyused	Pearson Correlation	–.193	–.255	–.125	–.250	–.840**	1
	Sig. (2–tailed)	.247	.123	.453	.131	.000	
	N	38	38	38	38	38	38

**. Correlation is significant at the 0.01 level (2–tailed).

T2-T1 = User Error

Additional correlations were in agreement with previous findings of our research (Table 3). Specifically, there were significant positive Pearson correlations between multiple conditions. Strong positive correlations included but were not limited to: user error at low frequency NBN and high frequency NBN, user error at low frequency WT and high frequency WT, between low frequency WT and low frequency NBN, and high frequency NBN and high frequency WT. There was a slight positive correlation between the last instance of HPD use and user error in all conditions. There was a slight negative correlation between frequency of HPD use and user error in all conditions.

Table 4: Questionnaire Data

Age	Mean	*(SD)*
18-24	20.97	1.37
Characteristic	***n***	**Percentage**
<u>Sex</u>		
Male	15	39.50%
Female	23	60.50%
<u>Confidence of HPD Use</u>		
Yes, believed	28	73.68%
No, not believed	10	26.32%
<u>Previous Experience</u>		
Yes	30	78.95%
No	8	21.05%
<u>Recent Use</u>		
Never Used	8	21.05%
Past Week	3	7.89%
Past Month	3	7.89%
Past 6 Months	12	31.58%
Past Year	3	7.89%
Past 5 years	9	23.68%
<u>Frequency of Use</u>		
Not Applicable	8	21.05%
Weekly	2	5.26%
Monthly	3	7.89%
At least 4 times/year	3	7.89%
At least 2 time/year	4	10.53%
Yearly	1	2.63%
Less than once a year	17	44.74%
<u>Awareness of Effect of Training</u>		
Yes	17	44.74%
No	21	55.26%

Characteristic	*n*	Percentage
<u>Training</u>		
No Training	22	57.89%
Manufacturer's Instructions	0	0%
Video or Tutorial	1	2.63%
By Friend or Family	9	23.68%
By Trained Professional	6	15.79%
<u>Perceived Difference in Fit</u>		
Yes	37	97.37
No	1	2.63%
<u>More Comfortable</u>		
Self-Fit	21	55.26%
Experimenter-Fit	17	44.74%
<u>Better Perceived Attenuation</u>		
Self-Fit	2	5.26%
Experimenter-Fit	36	94.74%
<u>Major</u>		
Communication Sciences & Disorders	24	63.16%
Biology	2	5.26%
Mechanical Engineering	2	5.26%
Undecided	1	2.63%
Anthropology	1	2.63%
Banking & Finance	1	2.63%
General Business	1	2.63%
Chemistry	1	2.63%
Political Science	1	2.63%
Marketing	1	2.63%
Integrated Marketing Communications	1	2.63%
Economics	1	2.63%
Bio-Chemistry	1	2.63%

The post examination questionnaire results in Table 4 revealed participant training knowledge. Of the 38 participants, 28 (73.68%) reported they believed they could knowledgably use foam ear plugs before this study. Participant HPD training was examined and showed that 22 participants (57.89%) reported receiving no previous training, 1 (2.63%) watched a tutorial video, 9 (23.68%) were shown by a friend or family member, and 6 (15.79%) were shown by a trained professional. None reported training from reading manufacturer's instructions. Furthermore, 21 participants (55.26%) reported they were not aware that a lack of training could reduce ear plug effectiveness.

Additionally, the questionnaire explored perception of experiment trials. 37 of the participants (97.37%) reported to perceiving a difference in ear plug fit. Of the participants, 21 (55.26%) perceived the self-fit ear plugs as more comfortable to wear. However, 36 (94.74%) participants reported better attenuation from the experimenter fit. Implications of the collected data will be further discussed in Chapter V.

CHAPTER V

DISCUSSION

Summary

High intensity noise can be dangerous to the hearing system. Chan, Ho, and Ryan (2016) explain that the two main causes of NIHL are brief exposure to high intensity impulse noise and prolonged or repeated exposure to steady high-level sounds. NIHL's symptoms range from tinnitus and a temporary threshold shift to a permanent threshold shift (Martin & Clark, 2015). NIHL commonly affects both ears in the higher frequencies, and intervention focuses on prevention with HPDs rather than treatment. Young adults especially are often exposed to dangerous noise without the proper protection. They expose themselves to loud noise in venues such as bars, nightclubs, and concerts, as well as with the use of personal music players (Keppler et al., 2015). Those that due utilize HPDs may not be using them correctly. NIOSH (1998) recommends the use of HPDs to avoid NIHL. Young adults may not yet work in industries that offer job-related hearing conservation training. Of the 38 participants, 28 (73.68%) reported they believed they could knowledgably use foam ear plugs before this study. However, participant HPD training (if any) was examined by the post-experiment questionnaire and 22 participants (57.89%) reported receiving no previous training,

User error is the result of erroneous fitting or utilization of a hearing protection device by the user, which causes a decrease in attenuation. User error can be calculated by subtracting the SF threshold, when the subject fits the ear plugs, from the EF threshold, when the experimenter fits the ear plugs. When donning hearing protection incorrectly, user error can be dangerous. The hearing system remains exposed to harmful noise. 21 participants (55.26%) reported they were not aware that a lack of HPD training could reduce ear plug effectiveness. Canetto (2009) proposes physical discomfort as a possible source of incorrect HPD fitting. Correct fit may cause discomfort, so the HPD is adjusted to feel more comfortable. 21 participants (55.26%) reported the self-fit ear plugs to be more comfortable than the experimenter fit. Additionally, wearing hearing protection devices with a high NRR can create a false sense of security. This false sense of protection can result in frequent misuse of hearing protection, which can lead to NIHL. Salmani Nodoushan et al.'s (2014) study showed that overprotecting with a high NRR in lieu of training in HPD use results in lower attenuation levels than proper use of an HPD with a lower NRR.

Two common sound stimuli used in audiometry are narrow band noise and warble tone. Narrow band noise is a restricted, band of frequencies surrounding a particular chosen frequency (Martin & Clark, 2015). Warble tone is a modulated pure tone that varies from the chosen frequency by a specifically measured amount (Martin & Clark, 2015). For the purpose of this study, user error was calculated, and then averaged across low frequencies (250Hz, 500Hz, 1000Hz) and high frequencies (2000Hz, 4000Hz, 8000Hz) for comparison in both the narrow band noise trial and the warble tone trial. As reported in Chapter IV, the difference between NBN and warble tone ranged from 1.98dB in the low frequencies to 0.45dB in the high frequencies. This is statistically significant. But as audiometric testing is performed using 5dB increments, this difference is clinically insignificant. However, this comparison shows an additional trend. Similar to when user error was compared at high and low frequencies, the difference of user error between NBN and warble tone was greater at the lower frequencies than the high frequencies.

In order to better understand the implications, utility, and connections between user error and frequency attenuation, the current research addressed two research questions. The first research question considered was: *The foam ear plugs' lower frequency attenuations will be affected by user error differently than the higher frequency attenuations.* The second research question was: *The foam ear plug's frequency attenuations of the two chosen stimuli, narrow band noise and warble tones, will differ.*

As stated in Chapter IV, summary data supported research question one, and did not support research question two. Specific to research question one, user error was larger in the lower frequencies compared to the higher frequencies across all participants. Regarding research question two, there was no significant difference between user error found in the NBN trial when compare to the warble tone trial.

Review of Literature

When analyzing the results of this research, determining if the data collected from the current research was consistent with literature described in the literature review was integral. Data from this study was consistent with the findings of multiple studies mentioned in the literature review, including Salmani Nodoushan et al. (2014), Alam et al. (2013), and Keppler et al. (2015). According to the results of this current study, user error was present across all participants regardless of reported training, with greater values in the lower frequencies than in the higher frequencies. Salmani Nodoushan et al.

(2014) mentioned varying levels of attenuation across different studies. They cited that factors such as head movement and ear canal size can easily affect an ear plug's attenuating ability. In this study, attenuation, when compared to baseline results, varied across participants. Participants were not restrained from head movement or change of posture within their sound booth chair. Additionally, this study only utilized one standard size of ear plugs, which showed variation amongst participants and their different ear canals. These factors are consistent with expected slight variations in findings when compared to other studies. Salmani Nodoushan et al. (2014) also utilized REAT method when testing participants, as it is considered the gold standard for threshold measurement in industrial environments. Alam et al. (2013) utilized both warble tone and NBN stimuli when conducting their experiment. They found that the difference in the average attenuating ability of ear plugs between the two stimuli was at the most 3dB. As their results are less than 5dB, their findings also show that the difference between stimuli is clinically insignificant. This statement agrees with our findings since, as seen in Figure 1, 1.98dB is a statistically significant difference between low frequency NBN and low frequency warble tone. The gap is also less than 5dB, meaning the difference is also clinically insignificant. Additionally, their results also show a trend of larger attenuation levels as frequencies increase. Their results agree with these findings of larger attenuation at the higher frequencies. Keppler et al. (2015) suggest young adults do not wear HPDs due to discomfort from their fit. Of the 38 participants, 37 (97.37%) perceived a difference in how the SF earplugs felt and the EF earplugs felt. Additionally, 21 (55.26%) felt that the SF earplugs were more comfortable. These findings are consistent with

Keppler et al. (2015), who mention young adults may not properly insert HPDs due to the uncomfortable feeling of a proper fit.

Implications toward functional application

When examining the collected data, user error is seen across all participants, including those who reported having been trained by a professional. This user error emphasizes the lack of adequate training seen in young adult college students. As a population vulnerable to dangerous noise exposure, young adult college students could benefit from having hearing conservation and HPD training programs introduced into their curriculum, especially students in majors or extracurricular activities pre-disposed to loud noise. Such students may include but are not limited to: music majors, band members, art students utilizing metal or wood, and engineering students. Proper training would benefit students across all majors in the long term.

Additionally, the post-experiment questionnaire revealed all 23 female participants were enrolled in the major Communication Sciences & Disorders (CSD). However, their major did not help or hinder their ability to utilize the foam ear plugs. All CSD female participants still experienced user error during testing. These results can support the speculation that basic knowledge regarding the need for hearing safety within their major was not enough to affect their performance. Further education and training within the CSD major would benefit the students and allow them to utilize their knowledge to educate others.

Review of accumulated results shows the difference in user error between narrow band noise trials and warble tone trials to be less than 5dB, and therefore, clinically insignificant. These findings show that such stimuli could be used during foam ear plug testing interchangeably. The results also show the attenuating ability of current foam earplugs to cancel out various stimuli somewhat equally when compared on the same frequency. Additionally, the results of this study could benefit HPD manufacturers. As they develop new and improved products, ear plug manufacturers can focus on materials and designs that better attenuate lower frequencies when designing, rather than trying to raise NRR in general.

When foam ear plugs are improperly inserted, gaps remain present between the ear canal wall and the HPD itself. Low frequency sound waves can travel through these gaps, while high frequency sounds waves may still be attenuated. Additionally, these gaps in improperly fit HPDs can explain why SF ear plugs cause less discomfort. When wearing a well inserted ear plug an individual might experience the occlusion effect, which is the perceived amplification of low frequency sounds that cannot escape the ear canal (Schow & Nerbonne, 2013). For example, hearing aids often have vents placed in the ear mold to allow the low frequencies to roll back out and reduce the occlusion effect. The improperly fit SF ear plugs, though more comfortable, are in actuality reducing the occlusion effect much like a vent in an ear mold. Ear muffs, however, have a much smaller margin for user error as acquiring an adequate seal around the ear takes less technical skill. Lack of a gap for low frequencies to travel through might make ear muffs the ideal choice for industrial settings, where lower frequency sound may be common. Because ear plugs better attenuate higher frequencies, even when inserted improperly, ear plugs might be the better choice for work with exposure to impact noise, such as firearms or metal work.

As stated in Chapter IV, there was a slight positive correlation between the last instance of HPD use and user error in all conditions, as well as a slight negative correlation between frequency of HPD use and user error in all conditions. Correlations regarding frequency of HPD use were negative due to the nature of the numerical values assigned to the questionnaire data answers. The scale assigned was inverse to the scale assigned to last use of HPDs. With this discrepancy taken into account, the Pearson correlations can be interpreted as positive. Therefore, the significant correlation between frequency of HPD use and when they last used HPDs can be considered positively correlated. Regarding time of last HPD use, the correlation showed that as the time since the last HPD use increased, there was a slight increase in user error in all conditions. This could be attributed to familiarity with the ear plug allowing for more confident and accurate insertion of ear plugs. The slight correlations regarding frequency of HPD use show that the more often the participant reported using HPDs, there was a slight decrease in user error in all conditions.

Recommendations for future research

Before making recommendations for future research, the limitations of this study must be acknowledged. Several variables were not accounted for in this research, such as a bilateral hearing loss occurring at a frequency other than 1000Hz, 2000Hz, or 4000Hz. Future research could include a more comprehensive screening process. Additionally, participation might also be skewed towards majors related to the study. Over half of the participant pool (63.16%) were of the major Communication Sciences and Disorders (CSD). The professors in such departments may offer extra credit in return for participation, where an English professor may not, which would not hold the same incentive across majors. Consequentially, all of the female participants were CSD majors. Future research could cultivate a more varying participant pool. Another limitation is the results of the subject-fit hearing evaluations may not be true to real world experiences due to the Hawthorne effect. The participants may take more care in inserting the foam ear plugs because they are aware that their performance will be observed and evaluated. Additionally, 5 participants (13.16%) displayed frequent false positive responses while determining thresholds. Such limitations could be offset by a less subjective measurement such as MIRE method. Finally, the sample size itself is small when compared to the population represented, so results were generalized.

While accounting for the limitations of this research, the results of this study suggested multiple directions for future study. One such direction includes adapting the methodology to utilize the microphone in real ear (MIRE) method, where a microphone is placed in the ear canal to record the sound that still travels past the foam ear plugs. Results could be compared to those acquired with REAT method. While REAT is reported to be preferred, this method would bypass the possibility of false reporting by the participant in the booth. Additionally, the study could be reproduced, and data analysis could be run across all frequencies, as opposed to averaging across high and low frequencies. Comparisons between each frequency could uncover a more refined trend of user error increase from higher frequencies to lower frequencies. This comparison removes the generalization for high and low frequencies, allowing for frequencies in the middle to be examined individually. This method could also be expounded to include inter-octaves.

Another direction to be explored could be the set-up utilized. An adjustment in sound booth seating with the same methodology would allow for more consistent results by ensuring the participant does not change the position of their head during testing. Because testing is performed in sound field, head movement and position may affect the consistency of how sound reaches the ear. Another change to the current study, while maintaining current testing procedures, would be offering different sized foam ear plug for those participants who do not best fit the standard size. More sizes would reduce the user error due to incorrect fitting due to wrong sizing. Furthermore, additional forms of HPDs could be tested for user error and compared across devices as well as within the selected frequencies. The study could include different forms of earplugs, as well as ear muffs.

Additionally, the stimuli used could be altered. As stated in Chapter IV, paired sample t-tests revealed a statistically significant difference in user error between high and low frequencies for both NBN and WT. Future research could probe this effect by using white noise and noise with a wider spread of frequency distribution than WT and NBN. Furthermore, paired sample t-tests showed a statistically significant difference in user error between NBN and WT in low frequencies. This effect was unexpected, but additional research is needed before making any assumptions about clinical applications. Further research would entail use of stimuli such as pediatric noise and white noise at low frequencies. Utilizing speech noise and multi-talker babble during testing would allow for the representation of real world attenuation values.

Further exploration of the participants and their training and attitudes towards HPD could be included in the questionnaire portion of the study. Additionally, a hearing conservation education session could be added to the end of the experiment to allow participants to leave the study with the appropriate knowledge to correct their user error. Participants could also return for follow up testing after the hearing conservation program to determine retention rate of learned materials.

In conclusion, this research raised numerous points of interest for further study. Specifically, more research is needed to better understand the effect of user error across different frequencies. The primary goal of this research was to determine the clinical effect of user error regarding the frequency attenuation of foam earplugs utilized by college-aged adults (18-24). While a secondary goal was to determine the clinical significance of narrow band noise and warble tone stimuli utilized in testing user error in foam ear plugs. This researcher hopes that this study, as well as future research derived from this study, will promote and support the exploration of user error in hearing protection devices, with the ultimate goal of helping audiologists in the education of proper HPD use and the dangers of HPD misuse.

Appendix A
Recruitment Email

Dear Students,

For my senior thesis, I am conducting a study on the effectiveness of foam ear plugs, and I am looking for participants! With your help, we can better understand how well foam ear plugs protect our hearing.

This study will take from 1 hour to 1 hour and 15 minutes of your time. In return you will be entered to win one of three $15 Starbucks gift cards, and be given extra credit in Dr. Lowe's CSD 356 and CSD359. (It is acceptable for Dr. Lowe's CSD359 to receive extra credit for recruitment of a male participant, aged 18-24, who is a student at the University of Mississippi)

To participate, schedule an appointment time, and visit us in the Audiology lab (George 101). There you would complete three prescreening tests to ensure normal ear health and hearing levels. If your hearing is normal, you would complete two hearing tests while wearing ear plugs with two different sound stimuli. Afterward, you would fill out a short questionnaire about your experience in the study.

Appointment times will be Wednesdays and Fridays from 1-5pm in 1 hour time slots (1-2pm, 2-3pm, 3-4pm, 4-5pm). At this time, slots up until Wednesday Oct.11th are filled. Open slots range from Friday Oct. 13th until Friday Nov. 10th.

In this study, your data will be completely confidential, and your results will not be connected to you in any way. You can stop at any time during the study with no penalty.

To schedule an appointment or to ask a question, email me, Alyse Lemoine, at ajlemoin@go.olemiss.edu, or Dr. Rebecca Lowe at rl1@olemiss.edu.

This study has been approved by UM's Institutional Review Board (IRB).

Thank you for your consideration of this study,
Alyse Lemoine
Honors Student

Appendix B
Data Collection Sheet

Participant # ______

Clear Otoscopy: yes / no   Tinnitus: yes / no

Healthy Tympanometry: yes / no

Baseline Screening

@25dB →	1k HZ	2k Hz	4k Hz
Puretone	**R:** yes / no **L:** yes / no	**R:** yes / no **L:** yes / no	**R:** yes / no **L:** yes / no

	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz
Baseline BL (WT)						
Baseline BL (NB)						
Trial 1-NB T1 (NB)						
Trial 1- WT T1 (WT)						
Trial 2-NB T2 (NB)						
Trial 2-WT T2 (WT)						
T1(NB) – BL(NB)						
T1(WT) – BL(WT)						
T2(NB) – BL(NB)						
T2(WT) – BL(WT)						
T2(NB) – T1(NB)						
T2(WT) – T1(WT)						

Appendix C
Post-Experiment Questionnaire

Participant # _____

Questionnaire

You are not required to answer any question, and may choose 'prefer not to answer' without fear of penalty on any question.

1. Please indicate your classification by grade:
   A. Freshman
   B. Sophomore
   C. Junior
   D. Senior
   E. Graduate Student
   F. Prefer not to answer

2. Please indicate your age in years:
   A. 18
   B. 19
   C. 20
   D. 21
   E. 22
   F. 23
   G. 24
   H. Prefer not to answer

3. Please indicate your gender:
   A. Female
   B. Male
   C. Other
   D. Prefer not to answer

4. Before this study, did you believe that you could knowledgeably use foam ear plugs?
   A. Yes
   B. No
   C. Prefer not to answer

5. Have you used foam ear plugs before today?
   A. Yes
   B. No
   C. Prefer not to answer

6. If you have, when was the last time you used them?
   A. In the past week
   B. In the past month
   C. In the past 6 months
   D. In the past year
   E. In the past 5 years
   F. Not applicable (have never used before today)
   G. Prefer not to answer

Participant # _____

7. How frequently do you use them?
   - A. Weekly
   - B. Monthly
   - C. At least four times a year
   - D. At least two times a year
   - E. Yearly
   - F. Rarely (Less than once a year)
   - G. Not applicable (have never used before today)
   - H. Prefer not to answer

8. How did you learn to fit your earplugs?
   - A. no previous training
   - B. read the manufacturer's instructions
   - C. watched a video or tutorial
   - D. was shown by a friend or family member
   - E. was shown by a trained professional
   - F. Prefer not to answer

9. Could you perceive a difference between the self-fit ear plugs and the experimenter-fit ear plugs?
   - A. Yes
   - B. No
   - C. Prefer not to answer

10. Which pair of ear plugs felt more comfortable to wear?
   - A. self-fit ear plugs
   - B. experimenter-fit ear plugs
   - C. Prefer not to answer

11. Which pair of ear plugs did you perceive to cancel out more sound?
   - A. self-fit ear plugs
   - B. experimenter-fit ear plugs
   - C. Prefer not to answer

12. Were you aware that a lack of training could reduce the effectiveness of foam ear plugs?
   - A. Yes
   - B. No
   - C. Prefer not to answer

13. What is your major?

____

Please place your school email for the gift card raffle and the course ID and section number for the class you wish to earn extra credit (if applicable) on the provided notecard, and place it in the provided container so that it will not be connected to your questionnaire or evaluation results.

Appendix D
IRB Approval Letter

THE UNIVERSITY of MISSISSIPPI

Office of Research and Sponsored Programs

8/28/2017

Ms. Lemoine
CSD

Dr. Lowe
CSD

IRB Protocol #:	**17-093**
Title of Study:	The Frequency Attenuations of Foam Ear Plugs Affected by User Error of College Students
Approval Date:	**08-28-17**
Expiration Date:	**08-27-18**

Dear Ms. Lemoine:

This is to inform you that your application to conduct research with human participants has been reviewed by the Institutional Review Board (IRB) at The University of Mississippi and approved **as Expedited under 45 CFR 46.110, categories 4 and 7.**

Research investigators must protect the rights and welfare of human research participants and comply with all applicable provisions of The University of Mississippi's Federalwide Assurance 00008602. Your obligations, by law and by University policy, include:

- Research must be conducted exactly as specified in the protocol that was approved by the IRB.
- Changes to the protocol or its related consent document must be approved by the IRB prior to implementation except where necessary to eliminate apparent immediate hazards to participants.
- **Please note that due to the nature of your research procedures, and pursuant to 45 CFR 46.116 (d), the IRB has waived the requirement for one element of consent.**
- A copy of the IRB-approved informed consent document must be provided to each participant at the time of consent, unless the IRB has specifically waived this requirement.
- Adverse events and/or any other unanticipated problems involving risks to participants or others must be reported promptly to the IRB.
- Signed consent documents and other records related to the research must be retained in a secure location for at least three years after completion of the research.
- Submission and *approval* of the *Progress Report* must occur before continuing your study beyond the expiration date above.
- The IRB protocol number and the study title should be included in any electronic or written correspondence.

If you have any questions, please feel free to contact the IRB at (662) 915-7482 or irb@olemiss.edu.

Sincerely,

Jennifer Caldwell

Jennifer Caldwell, Ph.D., CPIA, CIP
Senior Research Compliance Specialist

Appendix E
Consent Form

The University of Mississippi
Institutional Review Board
Protocol # 17-093
Approval Date 08-28-17
Expiration date 08-27-18
Signature

Consent to Participate in Research
Title: The Frequency Attenuation of Foam Ear Plugs Affected by User Error of College Students

Investigator
Alyse J. Lemoine
Department of Communication Sciences & Disorders
309 George Hall
University of Mississippi
University, MS 38677
(318) 407-0262
ajlemoin@go.olemiss.edu

Faculty Sponsor
Rebecca Lowe, AuD
Department of Communication Sciences & Disorders
309 George Hall
University of Mississippi
University, MS 38677
(662)-915-7574
rl1@olemiss.edu

Purpose of this study
We are conducting a study on the cancellation of specific frequencies when using foam ear plugs.

What you will do for this study
In order to gain accurate information we are asking you to participate in two screening tests and a hearing evaluation to ensure normal ear function.

> **1.** We will check your ear canal with the help of an otoscope in order to ensure the absence of wax that may block your ear drum.
> **2.** You will be required to sit still and remain quiet as a small rubber tip, will be placed in the opening of your ear canal and will create a soft low pitch tone across different pressure. This test will assess how well your ear drum moves.
> **3.** You will take a pure-tone audiometry test which will test your hearing threshold. Your hearing threshold is the softest level that you can detect different pitches. While you are in the sound booth we will present you with a series of beeps at several pitches via speakers, and you will have to notify us by raising your hand when you hear the beeps. The beeps will become softer with each presentation.

The second and third hearing evaluations will include measurement of hearing thresholds with foam ear plugs.

> **1.** While you are in the sound booth wearing the provided earplugs, we will present you with a series of narrow band noises or warble tones and you will have to notify us by raising your hand when you hear the narrow band noise or warble tone. The noises will become softer with each presentation.
> **2.** This process will be repeated.

Additionally, we ask that you complete a short survey to determine your experience with hearing protection in the past as well as what was experienced during this study.

Time required for this study
This study will be completed in 1 session, and will take about 1 hour to complete the testing and the survey.

Possible risks from your participation
You may feel temporary discomfort regarding ear plug fit, the otoscopy exam, or the tympanometry test. During otoscopy if the otoscope is not handled properly the tip may go too

far into your ear. You may run the risk of infection of the ear from equipment used in the study that may not be disinfected properly. You may feel performance-related stress from taking the hearing evaluations. During hearing evaluations, your ear may be exposed to unsafe noise levels that can be harmful to hearing.

The following appropriate measures were taken to avoid all risks associated with this research.

1. Throughout all testing, a strict adherence to Centers for Disease Control and Prevention (CDC) infection protocols will be followed (CDC, 2007).
2. During otoscopy, the proper procedure of bracing, as outlined in the American Speech-Language-Hearing Association guidelines for audiologic screening (ASHA, 1997), will be used to ensure that the otoscope tip does not go too far into the subject's ear canal. After otoscopy, otoscopy tips will be discarded.
3. During tympanometry, tympanometry tips will be disinfected with CIDEXPlus according to to disease control protocols set by CDC (CDC, 2007).
4. Audiometry will be conducted following American Speech-Language-Hearing Association (ASHA) standard operating procedure ensuring the safety of the subjects during testing (ASHA, 2005).

Benefits from your participation

You should not expect benefits from participating in this study. However, you might experience satisfaction from contributing to scientific knowledge. Also, answering the survey questions might make you more aware of habits you'd like to change – sometimes this can help lead to improved habits.

Incentives

You will be entered into a raffle for the chance to win one of three $15 Starbucks gift cards. With a goal number of participants of around 30 students, the approximate odds of winning a gift card are one in ten. Additionally, select professors may offer extra credit incentives in return for completion of this study.

Confidentiality

We will not put your name on any of your tests; instead a random number will identify your information. The only information that will be on your test materials will be your three hearing evaluation results and your questionnaire answers. All data collected will remain confidential and will be kept in a locked filing cabinet in a locked room.

Right to Withdraw

You do not have to take part in this study, and there is no penalty if you refuse. If you start the study and decide that you do not want to finish, all you have to do is tell Alyse Lemoine or Dr. Lowe in person, by letter, or by telephone at the department of Communication Sciences and Disorders, 309 George Hall, The University of Mississippi, University MS 38677, or (662)-915-7574. Whether or not you choose to participate or to withdraw will not affect your standing with the University, and it will not cause you to lose any benefits to which you are entitled. The researchers may terminate your participation in the study without regard to your consent and for any reason, such as protecting your safety and protecting the integrity of the research data.

IRB Approval

This study has been reviewed by The University of Mississippi's Institutional Review Board (IRB). The IRB has determined that this study fulfills the human research subject protections obligations required by state and federal law and University policies. If you have any questions or concerns regarding your rights as a research participant, please contact the IRB at (662) 915-7482 or irb@olemiss.edu.

Please ask the researcher if there is anything that is not clear or if you need more information. When all your questions have been answered, then decide if you want to be in the study or not.

Statement of Consent
I have read the above information. I have been given a copy of this form. I have had an opportunity to ask questions, and I have received answers. I consent to participate in the study.

Furthermore, I also affirm that the experimenter explained the study to me and told me about the study's risks as well as my right to refuse to participate and to withdraw.

☐ By checking this box, I assent that I am 18 years of age or older.

____
Name of Participant (print)

____
Signature of Participant Date

____
Signature of Investigator Date

NOTE TO PARTICIPANTS: DO NOT SIGN THIS FORM
IF THE IRB APPROVAL STAMP ON THE FIRST PAGE HAS EXPIRED.

Appendix F
Re-Consent Form

Post-Data-Collection Re-Consent Form

Because I did not fully tell you in the consent form about some of the procedures in this study, the IRB requires that I get your consent in order to use the information I collected from you.

- If you do not give your consent, there will be no penalty from me, your instructor, the department, or the school – this is completely your choice.

- If you do consent to the use of the information collected, please sign below and date it.

Following debriefing, I approve that the information collected from me in the *The Frequency Attenuations of Foam Ear Plugs Affected by User Error of College Students* study can be used by Alyse Lemoine

Signature of Participant Date

____

Printed name of Participant

____

Appendix G
UMSHC Approval Letter

The University of Mississippi
Oxford • Jackson • Tupelo • Southaven

Department of Communication Sciences and Disorders
Speech and Hearing Center
Post Office Box 1848
University, MS 38677-1848
(662) 915-7652
Fax: (662) 915-5717
cddepart@olemiss.edu

May 2, 2017

To Whom It May Concern:

Alyse Lemoine has permission to use the audiology clinic and equipment at The University of Mississippi Speech and Hearing Center to perform the necessary testing in order to collect data for her research project entitled: The Frequency Attenuations of Foam Ear Plugs Affected by User Error of College Students.

Thank-you,

Dr. Rebecca Lowe, AuD., CCC-A
University of Mississippi Co-Clinic Director; Director of Audiology

Accredited in Speech-Language Pathology by the Council on Academic Accreditation in Audiology and Speech-Language Pathology.
A Great American Public University
www.olemiss.edu

Appendix H
Procedure Script

Script

Consent Form

"Before we begin, please read over this consent form. If you have any questions, don't hesitate to ask. When you are finished, please place the consent form in the provided container."

Otoscopy

"This is an otoscope. I'm going to put the tip of this in your ear canal to check that it is clear. Do you have any questions? Please hold still"

Tympanometry

"This is a tympanometer. I'm going to put this tip in your ear to check how well your ear drum moves. You will feel it buzz. Do you have any questions? Please don't talk, chew, or swallow."

Referral

"We're sorry. Due to ________ you have not passed the screening process to continue with this study." (will follow the referral procedure of UM Speech and Hearing Center)

Hearing Evaluation

"You are going to hear a series of noises(WT)/buzzes(NB). I want you to say "yes" when you hear a noise. The noises will get softer with each presentation. Say "yes" every time you hear a noise, even if it's soft. Do you have any questions?"

Subject Fit Ear Plug HE

"I want you to insert these ear plugs into both ears. Let me know when you are ready… You are going to hear a series of noises. I want you to say yes when you hear a noise. The noises will get softer with each presentation. Say "yes" every time you hear a noise, even if it's soft. We will then repeat this test with a different set of noises. Do you have any questions?"

Experimenter Fit Ear Plug HE

"Please remove your ear plugs. Now, I am going to take a new pair of ear plugs and insert them into both of your ears myself. You may feel some discomfort… You are going to hear a series of noises. I want you to say "yes" when you hear a noise. The noises will get softer with each presentation. Say "yes" every time you hear a noise, even if it's soft. We will then repeat this test with a different set of noises. Do you have any questions?"

Questionnnaire

"This is a short questionnaire. It will ask about your experiences today in the study, as well as your history with hearing protection in the past. You are not required to answer any question, and may choose 'prefer not to answer' on any question. When you are finished, please place your school email for the gift card raffle and the course ID and section number for the class you wish to earn extra credit (if applicable) on the provided blank notecard, and place it in the provided envelope. It will not be connected to your questionnaire or evaluation results."

Debriefing

"Thank you for participating in this study. The purpose of this study was to measure the effect of user error on foam ear plugs' ability to cancel out noise. Your evaluation results will allow us to analyze the difference between how ear plugs cancel out noise when you insert them against when they are inserted by a trained experimenter. You were not told that we will be comparing the results so as to not change how you would insert the earplugs in a real-world situation. Do you have any questions? We ask that you do not share what you have experienced today with any other students participating in this study. Our contact information can be found on the copy of the consent form given to you at the beginning of the study. Please feel free to contact us with any further questions or concerns."

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