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Effects of Written Instructions on Field Real Ear Attenuation at Threshold Measurements

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EFFECTS OF WRITTEN INSTRUCTIONS ON FIELD REAL EAR ATTENUATION AT THRESHOLD MEASUREMENTS

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ABSTRACT

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Hearing protector fit-testing is an essential part of a hearing conservation program to ensure hearing protection devices are effectively protecting the wearer from hazardous noise. The National Institute for Occupational Safety and Health (NIOSH, 1996) hearing protection device (HPD) Well-Fit™ was used to measure the personal attenuation rating for each individual's 3M E-A-R Classic™ (3M, 2019) hearing protection device. The NIOSH HPD Well-Fit does not have official instructions for finding the personal attenuation rating. The purpose of this capstone research project was to investigate if there was a difference between personal attenuation rating (PAR) scores utilizing different methods of instruction (ascending, descending, or Békésy). Each method required the participant to go through different steps to obtain a threshold at each octave from 125-8000 Hz to calculate a PAR score. Three different written instruction methods were used to obtain PAR scores on 29 participants. A repeated measures analysis of variance showed no significant difference for PAR scores based on instruction method ($F = 2.46286$, $p = .09$). These results suggested no method of instruction used in this study produced a different PAR score than another and any of these methods of instruction would be appropriate to complete fit-testing. These results might be used to help simplify the process for completing fit-testing in real-world situations and streamlining hearing conservation programs.

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LIST OF ABBREVIATIONS

AL	Action Level
ANSI	American National Standards Institute
ASHA	American Speech-Language Hearing Association
dB	Decibel
dB HL	Decibel Hearing Level
EPA	Environmental Protection Agency
f-MIRE	Field Microphone in Real Ear
FRA	Federal Railroad Administration
HPDs	Hearing Protection Devices
MIRE	Microphone in Real Ear
MSHA	Mine Safety and Health Administration
NIHL	Noise-Induced Hearing Loss
NIOSH	National Institute for Occupational Safety and Health
NHCA	National Hearing Conservation Association
NRR	Noise Reduction Rating
OSHA	Occupational Safety and Health Administration
PAR	Personal Attenuation Rating
PEL	Permissible Exposure Limit
REAT	Real Ear Attenuation and Threshold
REL	Recommended Exposure Limit

rANOVA	Repeated Measures Analysis of Variance
SPL	Sound Pressure Level
TWA	Time Weighted Average

CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

Noise-induced hearing loss (NIHL) is a significant negative health outcome from exposure to hazardous noise in the workplace for over 22 million people in the United States (Tak & Calvert, 2008). Noise-induced hearing loss can lead to a breakdown in verbal/auditory communication as well as contribute to social isolation. Federal agencies like the Occupational Safety and Health Administration (OSHA) sought to create regulations that workplaces must follow in order to protect workers from the negative effects of high-level noise exposure. When noise exposure levels meet or exceed 90 dBA averaged over eight hours, employers must require workers to wear hearing protection devices (HPDs). The Occupational Safety and Health Administration partnered with the National Institute for Occupational Safety and Health (NIOSH) and the National Hearing Conservation Association (NHCA) and developed best practice guidelines that stated HPDs should be implemented when occupational noise exposure reaches 85 dBA averaged over eight hours of exposure time (National Hearing Conservation Association & Alliance, 2008). Hearing protection devices provide a certain amount of noise reduction, termed "attenuation," from high sound levels but the noise reduction rating (NRR) on the package is not indicative of real-world performance of HPDs (Berger et al., 1998). The NRR is a laboratory-based measurement that attempts to statistically predict the amount of attenuation the wearer would obtain (Environmental Protection Agency, 2009). However, Berger et al. (1998) determined that less than 5% of the population actually achieves the amount of attenuation listed on HPD packaging labels specifying the NRR of individual products.

In order to measure the individual effectiveness of HPDs, different methods of individual fit-testing can be performed including a real ear attenuation and threshold (REAT) microphone in real ear (MIRE) and loudness balancing. These methods were first tested in the laboratory and then adapted for measurement in the field. Fit-testing is important for employers because it allows them to know if the type of HPDs provided to workers are providing the adequate amount of protection and if they need to further train employees on the proper use of HPDs. Manufacturers have developed their own software programs that run field fit-tests to measure HPD attenuation effectiveness. Byrne et al. (2016) analyzed the performance of three different fit-test systems and found the method for fit-testing did not have a significant effect on the resulting attenuation measurements. The effectiveness of HPDs can be quantified as a personal attenuation rating or a PAR score, which is a measurement of the amount of attenuation each ear obtains from an HPD. Each type of software uses a different method for calculating the PAR score. Murphy (2014) summarized the different ways fit-testing software calculated these scores as a reference for users.

Murphy, Themann, and Murata (2016) implemented the HPD Well-Fit, a field fit-testing system developed by NIOSH, on workers on an oil-rig to assess the performance of this particular fit-testing system. The researchers wanted to assess the amount of attenuation workers were getting with their HPDs, demonstrate the importance of training individuals to fit HPDs, and report the overall time it took to implement individual fit-testing in the workplace. Murphy et al. used two differing methods of instructions to obtain PAR scores in this study, one of which was distributed with the device and another that was updated by an audiologist. Researchers found that in two separate data collections, 39% of workers in the group that received the standard instructions and 44% of workers who received the updated instructions did not reach the target PAR score of 25 dBA when initially fitting their HPDs. After training, 89% of workers who received standard instructions and 85% of workers who received modified instructions achieved what was deemed to be an appropriate PAR score, indicating the effectiveness of individualized fit-training programs.

Methods for obtaining the hearing thresholds necessary to calculate PAR scores vary. Currently, the HPD Well-Fit (NIOSH, 1996) system utilizes the method of adjustment for obtaining a hearing threshold at a specific frequency. The system uses the occluded and unoccluded thresholds to calculate the PAR score. The purpose of the current study was to determine if utilizing different test instructions would alter the PAR scores measured on individual ears. The results of this study would further inform those implementing individual fit-testing with regard to choosing the type of instructions to give participants for threshold measurement when using HPD Well-Fit™ technology.

Research Questions

Q1 Is there a difference in PAR scores obtained with three different versions of written instructions (descending, ascending, or Békésy)?

Q2 Is there evidence of a learning effect on PAR scores measured sequentially?

Hypotheses

H_{01} There will be no significant difference in PAR scores obtained utilizing different versions of written instructions.

H_{02} There is no difference in PAR scores measured for the first versus third set of instructions.

CHAPTER II

REVIEW OF THE LITERATURE

Hearing Protection Devices

Hearing protection devices (HPDs) were developed with the goal of attenuating the sound pressure level reaching the ear in order to prevent auditory damage. Their use is widespread and the type of HPD used is dependent upon the user and the amount of sound exposure to which they are subjected. In the United States, federal agencies such as OSHA (1983c), the Mine Safety and Health Administration (MSHA, 2019) and the Federal Railroad Administration (FRA, 2007) are responsible for creating regulations on when personal protective equipment (including HPDs) are required to be worn in the workplace. The National Institute for Occupational Safety and Health (1998) establishes best practices with regard to hearing loss prevention.

The three main types of hearing protection are earmuffs, earplugs, and semi-insert earplugs. The earmuff style is designed to surround the pinna of the ear and cover the ear canal. Plastic earcups seal around the pinna using gel, foam, or liquid-filled cushions while an adjustable headband holds them in place (Rawool, 2012). They can be used alone or in addition to earplugs and generally come in one size, meant to fit all users.

In contrast, earplugs are placed directly within the ear canal and come in many sizes to accommodate different sized pinnae and ear canals. Types include roll-down foam, pre-formed, and custom molded. Roll-down foam must be compressed before they are inserted and are made of high-density materials such as polyvinyl chloride. These are the most widely used type of hearing protection. Pre-formed earplugs are made from flexible materials and have flanges or rings that create a seal in the ear canal. The flanges are attached to a stem for insertion, which means they do not need to be rolled down before insertion. Custom molded earplugs are unique to the individual wearing them as they are formed from custom made impressions of the ear canal. These earplugs fill the auditory canal of the ear, creating a seal to block incoming noise. Roll-down foam and pre-formed earplugs can be just as effective as custom molded if they are used properly and inserted correctly.

Semi-insert earplugs are held in place by plastic headbands and may either be seen as a cap covering the entrance to the ear canal or be inserted inside the ear canal. The materials can be made from foam, silicone, or vinyl and may have flanges similar to those seen on pre-formed earplugs.

Hearing Protection in the Workplace

For the workplace, OSHA (1983a) requires hearing protection to be worn if the noise exceeds 90 dBA time-weighted average (TWA); use is optional for TWAs at or above 85 dBA unless the worker has not had a baseline hearing test or experienced a shift in hearing, in which case HPD use is mandatory at 85 dBA TWA. Noise exposure above 90 dBA TWA level is considered to be hazardous on a daily basis. Noise exposure measurement is obtained by using a noise dosimeter to measure the sound pressure levels integrated over time during the course of the work shift and applying an A-weighted curve to the measurement to determine the decibel level. The Occupational Safety and Health Administration assumes damage to the ear can occur if individuals are repeatedly exposed to a 90 dBA TWA sound for more than eight hours a day over the course of a

40-year career. As the intensity of the sound increases by 5 dB, the amount of permissible exposure time is halved (OSHA, 1983a). For example, if an environment is measured at 90 dBA TWA, the exposure is not considered to be hazardous if they are exposed for less than eight hours. If the sound is measured to be 95 dBA TWA, the equivalent permissible exposure time drops to four hours. However, NIOSH (1998) published best practice guidelines that recommended implementing hearing protection at 85 dBA TWA and measuring noise exposure using a 3 dB exchange rate. This means a workplace noise exposure measured at 88 dBA TWA would have a four-hour recommended exposure limit (REL) for a worker. If unprotected exposure to workplace noise levels exceed these limits, the worker might develop a noise-induced hearing loss (NIHL). The employer has the option of implementing NIOSH recommendations, which are more stringent and protective for the worker.

Noise-Induced Hearing Loss

Tak and Calvert (2008) estimated that approximately 22 million people in the United States are exposed to hazardous noise greater than 85 dBA in the workplace and at risk of NIHL. Noise-induced hearing loss can be classified as a temporary or permanent shift in audiometric hearing thresholds due to prolonged exposure to loud noise (Hong, Kerr, Poling, & Dhar, 2013). It is a result of both environmental and worker factors, causing damage to the sensory hair cells and other structures in the cochlea and neural connections in the auditory pathway. Exposure to loud noise might result at first in a temporary threshold shift and might recover within the first 24 to 48 hours (Humes, Joellenbeck, & Durch, 2005). Over time, exposure to noise could cause irreversible damage to the outer hair cells in the cochlea and they lose their ability to transmit sound signals to the brain (Hong et al., 2013). High intensity and extended exposure to noise increases the incidence of NIHL. Symptoms of NIHL include reports of muffled sounds, impaired communication, and tinnitus (Hong et al., 2013).

Using HPDs is a method for protecting the ear from hazardous noise exposure and ultimately from NIHL. The high prevalence of workplace noise exposure led federal agencies to implement regulations and guidelines regarding hearing protection in the workplace (NIOSH, 1996).

Workplace Hearing Protection Requirements

The following section reviews U.S. federal regulations that relate to when a worker is required to wear hearing protection, selection of hearing protectors and attenuation requirements, and contrasts those with recommended best practice by NIOSH (1998).

Noise Exposure Measurements

Federal regulations written by OSHA (1983c), MSHA (2019), and FRA (2007) each stated different permissible exposure limit (PEL) for individuals. The PEL states at what level of noise exposure noise control is mandated. Noise control (engineering and/or administrative) is the first level of intervention to prevention NIHL. If noise control is not feasible, then hearing protection becomes mandatory for workers exposed above the PEL. The PEL is expressed in terms of a TWA, which is a measurement taken over time. Regulations put forth by OSHA state PEL measurements incorporate sounds between 90 and 140 dBA. The same guidelines from OSHA are followed by the FRA while MSHA incorporates sound levels from 90 dBA to at least 140 dBA, which recognizes the advancements in contemporary noise-sampling instruments that have a broader response range now as compared to those of the late 1970s and early 1980s. Action level (AL) is the TWA exposure level at which employers are required to implement hearing conservation programs that include multiple components: noise measurement, noise control, hearing protection devices, employee education and training, audiometric monitoring, recordkeeping, and hearing conservation program effectiveness.

The OSHA (1983a) AL is measured by incorporating all sounds from 80 to 130 dBA TWA. The exchange rate is classified as the rate at which noise exposure accumulates or the change in dB TWA for halving or doubling of allowable noise exposure time. A 5 dB exchange rate is utilized by OSHA, MSHA (2019), and FRA (2007). These PEL and AL metrics are summarized for each of the three U.S. federal hearing conservation regulations in Table 1. These regulations are required by law in workplaces overseen by these agencies. In 1998, NIOSH released guidelines that were not mandatory but were recommended as a best practice for workplace safety and the prevention of NIHL; the guidelines specified a recommended exposure level (REL) at 85 dBA TWA.

Table 1

Comparison of Federal Regulations and Guidelines in the United States

	OSHA, FRA, & MSHA	NIOSH
Permissible Exposure Limit (PEL)	90 dBA TWA (integrating all sounds from 90-140 dBA)	85 dBA TWA (integrating all sounds from 80 to 140 dBA)
Action Level (AL)	85 dBA TWA (AL is exceeded when TWA is >85 dBA, all sounds from 80-130 dBA)	Not applicable
Exchange Rate	5 dB	3 dB

Hearing Protection Device Use Requirements

Federal regulations regarding the exposure limits and conditions for the use of HPDs depend on the agency. The Occupational Safety and Health Administration (1983a) states that hearing protection is optional for workers with a TWA of 85 dBA or less and mandatory at 90 dBA TWA and above except for new employees and those who have had significant shifts in their pure-tone thresholds from previous tests. These employees must wear hearing protection at 85 dBA TWA and above. These requirements were also put forth by MSHA (2019) but did not state the amount of attenuation required. At levels of 105 dBA TWA, dual protection, meaning earplugs and muffs, are required (MSHA, 2019). The FRA (2007) followed the OSHA guidelines but made stipulations about the employee’s ability to understand and respond to communication and audible warnings. The NIOSH (1998) guidelines recommended that

HPDs be worn in all environments measured at 85 dBA TWA and above and dual protection be implemented at noise exposures greater than 100 dBA TWA.

Selection of Hearing Protection Devices

The types of HPD provided and the amount of attenuation specified for each agency are summarized in Table 2.

Table 2

Hearing Protection Device Type and Attenuation Listed by Federal Agencies

	OSHA	MSHA	FRA	NIOSH
Type of HPD	Offer variety—at least one type of plug and muff	Must include two types of plugs and muffs	Variety of suitable HPDs with a range of attenuation levels	Offer variety
Amount of Attenuation Required	Protect to 90 dBA TWA or to 85 dBA TWA after threshold shift; 50% derating	No method specified	Always use noise reduction rating (NRR) with -7	Protect to 85 dBA TWA; derating 25% muffs; 50% slow-recovery plugs; 70% other

Noise Reduction Rating

The EPA (2009) wanted to find a way to make understanding HPD attenuation easy for consumers and consistent across products, so they developed the NRR, which is measured in the laboratory. All hearing protection devices manufactured in the United States have an NRR rating labeled on the product. The rating is calculated from laboratory REAT measures and predicts the level of sound protection provided to 98% of all workers who use the devices as instructed (EPA, 2009). The NRR value comes from the mean results of ten test subjects in highly regulated laboratory settings. The laboratory NRR was meant to be applied to C-weighted noise levels but occupational noise measurements use A-weighting levels (Meinke, 2013). Researchers have demonstrated that less than 5% of the population has obtained the amount of attenuation listed as the NRR (Berger et al., 1998). A serious concern has subsequently arisen due to employers selecting HPDs with the highest labeled NRR without regard to other factors that influence the actual attenuation obtained by a wearer including the actual fit of the HPDs (Berger et al., 1998). Murphy et al. (2016) wanted to assess how accurate the noise reduction of hearing protection was for individual workers on an oil-rig. They implemented a training program in addition to measuring the personal attenuation achieved by workers to demonstrate how the NRR applied in real world situations. The results indicated the NRR had very little predictive value for estimating one's attenuation and actual protected noise exposure level. Attenuation scores varied greatly among the workers. This study is detailed further in this chapter. Further testing needed to be developed to compensate for the fact that the NRR was not reflective of real-world performance of HPDs. The NRR was originally a statistic meant to emphasize the importance of attenuation values and was incorporated into the OSHA (1983b) Hearing Conservation Amendment. Gauger and Berger (2004) revealed up to a 20 dB variability in attenuation values between subjects and the NRR statistic was not good at predicting the attenuation performance for individual wearers. This led the industry to begin developing field fit-testing equipment and explore the implementation of individual fit-testing in the workplace.

In an effort to make the NRR more reflective of real-world performance, NIOSH proposed that a derating be applied (Meinke, 2013). In this instance, the NRR was multiplied by a percentage depending on the type of HPD (Meinke, 2013). For earmuffs, the NRR was multiplied by .75. Foam earplugs and custom-fit earplug were multiplied by .50 and all other types of earplugs were multiplied by .30. Derating was an attempt to make the NRR more realistic.

Best Practice Recommendations

The NHCA (2008) developed a best practice bulletin as an informational program. For this bulletin, NHCA and OSHA came together to describe the newest trends in individual fit-testing and outlined practices that would be most beneficial to implement. They determined fit-testing was the preferred means of measuring an individual's attenuation with a particular HPD.

Importance of Fit-Testing

Fit-testing is done for many reasons. Professionals must account for the variability in attenuation measurement due to individual and ear factors. Factors included the workers' inclination to wear hearing protection, susceptibility to NIHL, and the variability in size and shape of ears. Fit-testing allows professionals to deem which hearing protection would be advantageous for workers to utilize in specific noise environments based upon their noise exposure profiles. Ultimately, the success with hearing protection is dependent upon the individual's motivation and training to wear it regularly and properly. Fit-testing gives professionals a way to work directly with employees and train them in the correct way to use their hearing protection. Performing fit-testing also ensures the attenuation of the HPDs provided by the employer is adequate for the noise exposure and provides an opportunity to educate employers about what type(s) of hearing protection might be best suited for their employees.

Laboratory Attenuation Measurement Method

Measuring attenuation is an essential factor in ensuring the proper functioning of HPDs to prevent NIHL (Rawool, 2012). The NRR is a mandated label printed on the package of hearing protection that estimates the attenuation of the device based upon REAT measurements by the EPA (2009). In addition to REAT measurements, MIRE could also be used to measure attenuation. The American National Standards Institute (ANSI, 2013) has published recommendations regarding the laboratory measurement of attenuation used to label the NRR on HPD packaging.

Real Ear Attenuation at Threshold

Measurements of REAT are based upon the minimum level of sound a participant can hear without (or unoccluded) and with (occluded) an HPD (Berger, 1986). The minimum levels, or thresholds, obtained from both conditions are compared to find the threshold shift. The calculated difference between the conditions is the REAT. This testing can be performed under different types of headphones to measure earplug attenuation in the laboratory. This situation allows the researcher to control many aspects of the testing including the environment, ambient noise, and the fit of the hearing protector. Measurements obtained are subjective, meaning they depend on the subjects' understanding of the instructions. In addition, laboratory testing is not reflective of real-world performance since variables are well controlled. Real ear attenuation at threshold testing has also been developed for the field.

Microphone-in-Real-Ear

Microphone-in-Real-Ear is a laboratory test that involves placing a probe microphone outside the hearing protector as well as one in the ear canal under it. The purpose is to determine the difference in the sound pressure levels in two different conditions: in the ear canal with and without the HPD or underneath versus outside the HPD (Berger & Voix, 2017). The difference between the unoccluded measured levels and occluded is referred to as insertion loss (IL) and requires two separate measurements. The difference outside the HPD versus underneath is labeled noise reduction (NR) and is obtained by taking simultaneous measurements with two microphones, making it more ideal and adaptable for field use (Berger, Voix, & Kieper, 2007). According to Berger and Voix (2017), MIRE can be considered an objective version of REAT since different levels are measured at the same point in the auditory system in both occluded and unoccluded conditions and do not depend on the subject responding to the stimulus (Voix & Laville, 2009).

Field Attenuation Measurement Approaches

Field attenuation measurement techniques were developed to evaluate the attenuation performance of individual HPDs, otherwise known as fit-tests. Methods such as field REAT, field microphone-in-real-ear (f-MIRE), and loudness balancing are available through different developers for public use.

Field Real Ear Attenuation and Threshold

Hearing protection devices are not always used in ideal situations like the laboratory so field REAT testing protocols were adapted. Another reason for these adaptations was due to the overestimation of the NRR in the laboratory (Berger, Franks,

& Lindgren, 1996). Field REAT attempts to measure how the HPD performs in the real world. This approach is performed under circumaural headphones and tested in non-laboratory settings. Kabe et al. (2012) recognized that the principal problem with field REAT was its time-consuming nature. Test duration averaged approximately 30 minutes per person. Test time could be shortened by limiting the number of frequencies tested but the more frequencies that are tested, the more accurate the attenuation measurement. The HPD Well-Fit device developed by NIOSH (1996) is an example of a system that utilizes REAT for field testing. Through a partnership with Michael and Associates, this system is marketed as the FitCheck™ solo system (Murphy, 2014). This device was utilized in the present study.

Field Microphone-in-Real-Ear

Field microphone-in-real-ear (f-MIRE) involves taking simultaneous measurements of the sound pressure level outside and underneath the HPD using probe microphones conducted outside of the laboratory setting. The difference in the levels is taken and reported as the attenuation value after correcting for acoustic and measurement variability. The E-A-Rfit™ (Murphy, 2014) was created by 3M (2019) and is a fit-check system that uses the MIRE method. This device requires the use of a sound-field speaker in addition to microphones placed inside the ear canal under the HPD. The measured attenuation is the difference between the sound pressure level at the speaker and at the in-ear microphone.

Loudness Balancing

Loudness balancing is another method for fit-testing HPDs based upon subjective auditory responses. For this attenuation measurement, the individual wears headphones with no earplugs and is instructed to adjust the loudness (or intensity) of the stimulus in each ear until they are judged to be equal. Then one earplug is inserted and the same process is repeated. Finally, the other earplug is placed and the test is repeated. The difference between the levels of loudness of occluded and unoccluded conditions provides an indication of the attenuation of the HPD at different frequencies. This test is also considered subjective since the listener determines when the loudness is equal. The VeriPRO® device marketed by Honeywell uses loudness balancing to measure the PAR for each employee (Byrne et al., 2016). Testing a range of frequencies from 125 to 8000 Hertz (Hz), the VeriPRO can measure the effectiveness of earplug fit.

Personal Attenuation Rating

Personal attenuation rating is an individualized attenuation score provided by each of the fit-testing software programs. Murphy (2014) categorized the different fit-test systems and the methods by which they calculated PAR scores. The PAR score estimates the mean attenuation achieved for the hearing protector measured on an individual ear. By measuring each ear individually, fitting issues can be addressed while bilateral measurements predict overall protection in a noisy environment. This method of describing attenuation differs from the NRR as it represents the actual attenuation obtained by an individual who fits his or her own protector while the NRR is a mean of laboratory experiments in which the HPDs were placed by trained professionals.

The obtained PAR score is subtracted from the A-weighted sound level measurement to calculate protected noise levels. The HPD Well-Fit (NIOSH, 1996) device uses the A-weighted attenuation when calculating PAR scores at the determined test frequencies. The formula is:

$$PAR_N = L_A - L_{A\text{-}Atten}$$

In this equation, N represents the number of test frequencies, L_A is the A-weighted noise, and $L_{A\text{-}Atten}$ is the measured attenuation subtracted from the A-weighted noise.

Hearing Protection Device Well-Fit

The NIOSH (1996) HPD Well-Fit measures the REAT under headphones using one of three hearing threshold measurement methods to obtain a PAR score: Békésy, method of adjustment, and Hughson-Westlake. The more commonly used “method of adjustment” provides an estimate of the attenuation of the hearing protector (Byrne et al., 2016). The subject is in control of the stimulus presentation level through the use of the scroll wheel on a computer mouse. The intensity of the stimulus increases when the wheel is rolled upward and decreases when the wheel is scrolled downward. The test-takers are fitted with Sennheiser HDA 200 sound-isolating earphones or Audiometric Circumaural Tuned Headsets provided by Michael and Associates (Byrne et al., 2016). Subjects are instructed to reduce the level of the stimulus until it is barely audible and then click the mouse. The system increases to a higher start intensity for the stimulus based upon the previous threshold and restarts the task. The subject repeats the process until three thresholds are obtained within 6 dB of one another (Byrne et al., 2016). The tolerance of 6 dB can be modified by the operator if desired; however, the use of the 6 dB criterion is consistent with a ±5 dB test/retest reliability for auditory threshold measurements in adults (Stuart, Stenstromb, Tompkins, & Vandenhoff, 1991).

The test stimuli are one-third octave band noises from 125 to 8000 Hz. (Murphy et al., 2016). The test is completed in both occluded and unoccluded conditions and the resulting hearing thresholds are used to calculate HPD attenuation in both an individual ear and binaurally. The PAR equation described above is used to assign a PAR score to the protector for each ear and wearer. Since the HPD Well-Fit (NIOSH, 1996) relies upon patient response patterns similar to those obtained in conventional hearing testing, a review of air-conduction pure-tone audiometry is relevant and is discussed later in this section.

Research performed by Murphy et al. (2016) used the HPD Well-Fit (NIOSH, 1996) to assess the noise reduction of HPDs for individual workers, to demonstrate the effectiveness of training on the amount of protection achieved, and to measure the time required to implement hearing protector fit-testing in the workplace. Two data collection periods were held in 2012 and 2013 where 75 and 86 participants were tested, respectively. The two procedures were similar but had several differences worth noting. Participants wore the hearing protection of their choice including custom-fit earplugs, pre-molded earplugs, and formable earplugs. Murphy and colleagues used FitCheck circumaural headphones manufactured by Michael and Associates with an output maximum of 75 dB SPL (sound pressure level) in the 2012 data collection session. In 2013, they upgraded to Sennheiser HDA-200 circumaural audiometric headphones with extensions to increase the volume of the ear cup. These headphones had a maximum output of 85 dB SPL. Murphy et al. instructed workers to fit their HPDs in place with no instruction from the testers and then measured their PAR scores using the HPD Well-Fit software. The goal was for participants to reach a minimum 25 dB PAR score. If they were successful, they were appropriately trained in fitting HPDs. If not, they were reinstructed on how to fit their HPDs and the test was performed again. The PAR score was calculated using results from 500, 1000, and 2000 Hz and for both data collection sessions, the method of adjustment was used. The most significant change was in the instructions given to the participants. In 2012, the instructions read:

> You will hear a series of pulsing sounds through the headphones. They will start at a comfortably loud level. Your task is to adjust the volume of the sounds until you can just barely hear them. Use the scroll wheel of the mouse to make the sounds louder or softer. When you have adjusted the level to the point where you can just barely hear it, click the scroll wheel to move on to the next sound. Do you have any questions? (p. 8)

During the 2013 data collection, the instructions were altered slightly due to a change in the tester. The changes are noted in italics below:

> You will hear a series of pulsing sounds through the headphones. They will start at a comfortably loud level. Use the scroll wheel of the mouse to make the sounds louder or softer. *Scroll down until you can no longer hear the sounds, then slowly scroll up until you can just barely hear them.* When you have adjusted the level to the point where you can just barely hear it, click the scroll wheel to move on to the next sound. Do you have any questions? (p. 8)

The authors noted the change in instructions but did not discuss how these instructions might have altered the results. The descending technique from 2012 required different response patterns than the ascending technique from 2013.

Murphy et al. (2016) found 39% of participants did not reach the minimum 25 dB PAR on the first fit in 2012 and 44% in 2013. After reinstruction, 89% (2012) and 85% (2013) of workers reached the minimum PAR score. This emphasized the importance and effectiveness of implementing fit-testing in the workplace because it ensured that workers were trained and adequately protected. Additionally, the researchers found an improvement in test times from unoccluded to occluded conditions for both ears. This was believed to be due to the learning effect. Test times in 2013 were longer but Murphy and colleagues attributed that to the change in instructions. No significant differences were noted in the standard deviations between frequencies and years.

Hearing Threshold Testing

Pure-tone audiometry can be used to assess whether one has hearing deficits in addition to providing information on the possible type, degree, and configuration of hearing loss (Roeser, Buckley, & Stickney, 2000). An audiologist can determine an individual's hearing thresholds by instructing them to respond to tonal stimuli presented under earphones or in sound-field. A device known as an audiometer allows the audiologist to perform pure-tone audiometry. The audiologist has the ability to increase and decrease the frequency, measured in Hz, and the intensity, measured in decibels (dB) of the tones (Walker, Cleveland, Davis, & Seales, 2013). Pure-tone audiometry is performed as either a screening or a threshold search where tones are presented across the spectrum of frequencies from 250 to 8000 Hz in either octave or half-octave intervals (Walker et al., 2013). The intensity of the tones is altered by the audiologist and threshold is determined to be the softest intensity where the patient can hear the tone 50% of the time (American Speech-Language-Hearing Association [ASHA], 2005). Basic procedures to follow to obtain audiometric thresholds can be found on the ASHA website. These procedures are based on ANSI (2004) guidelines designed to provide a standard and minimize the variability in testing. The method of instructing individuals and types of stimuli might vary (Dancer, Ventry, & Hill, 1976).

Pure-tone audiometry can be obtained in either an air conduction or bone conduction condition. Air conduction is a subjective measure of hearing thresholds and is used to evaluate the physiologic status of the outer, middle, and inner ear mechanisms (Walker et al., 2013). The auditory stimulus can be introduced via circumaural, supra aural, or insert earphones. Air conduction thresholds can be used in conjunction with an audiometric test battery to identify the degree and configuration of hearing loss. Bone conduction audiometry is another subjective measure of hearing thresholds but primarily assesses the inner ear mechanisms (Walker et al., 2013). Bone conduction thresholds can be used with air conduction thresholds to determine if the loss is sensorineural, conductive, or mixed in nature (Martin & Clark, 2000).

Manual Hearing Threshold Methods

Manual methods for obtaining pure-tone hearing thresholds include ascending and descending approaches. The ascending technique involves presenting the tone below the threshold of hearing and increasing it in 5 dB steps until the listener indicates he or she can just barely hear the tone. The descending approach involves presentation of the tone at a suprathreshold level—that is, a level that is known to be above the individual's thresholds—and the operator reduces the tone in 5 dB steps until the listener indicates the tone is no longer heard. A recommended procedure was released by ASHA (2005) for obtaining thresholds, known as the modified Hughson-Westlake method, which is now considered standardized best practice. In this case, the tone is presented at a suprathreshold level, which is between 30 and 40 dB HL if the patient is known to have normal hearing sensitivity and up to 70 dB HL for patients with a moderate hearing loss (Carhart & Jerger, 1959). The stimulus is decreased by 10 dB until the patient no longer responds. The tone is then increased in 5 dB increments until a response is obtained again. Threshold levels are determined by the lowest intensity at which the patient is able to respond to the stimulus 50% of the time (ASHA, 2005).

Tyler and Wood (1980) performed a study comparing the manual methods of obtaining threshold including a descending approach, the 1978 ASHA method, and a shortened version of the ASHA method. This shortened version implied only two responses were required to determine threshold unlike the three required in the ASHA method. Using 14 participants, they tested 1000 Hz a total of 15 times for each method. The researchers found no significant differences in the three methods when it came to threshold estimates, standard deviations, and false positives. Tyler and Wood noted the ASHA method took longer than the other two methods of instruction.

Listener Instructions

The type of instructions given in addition to the method of threshold search is an essential factor in the overall determination of a patient's hearing sensitivity threshold. It was observed that instructions could be susceptible to interpretation and could introduce measurement variability. Dancer et al. (1976) studied the effects of instructions on pure-tone thresholds and false alarms (or false positives). The authors utilized three forms of instructions with 20 subjects. The first form of instruction was conventional hearing test instructions presented by Carhart and Jerger in 1959 in their study of preferred methods of threshold determination. The alterations of instructions included stricter criteria, where the audiologist did not encourage guessing, and more lax instructions, where guessing was encouraged (Dancer et al., 1976). Their results indicated false alarms were affected by instructions but hearing sensitivity thresholds did not vary significantly with instructions (Dancer et al., 1976). Instructions that encouraged the participants to guess even if they were not sure they heard the stimulus provided a higher number of false alarm responses. If instructed to not guess, Dancer and colleagues found fewer false alarms were measured.

Method of Adjustment

Gustav Fechner (cited in Gelfand, 2010) was known for introducing the different psychophysical methods of perception. Fechner focused his research on all sensory perceptions but his classical methods for assessment were adapted by audiologists to study hearing threshold measurement. The purpose of his research into perception was to determine the relationship between a sound presentation and how the subject perceived it (Gelfand, 2010). This was accomplished by varying some aspect of a stimulus (frequency, intensity, etc.) and the individual's response was recorded. For example, one might vary the intensity of a stimulus and the lowest level at which the sound was heard was estimated to be the absolute sensitivity (Gelfand, 2010).

One psychophysical method that is a modification of the method of adjustment is known as Békésy tracking (Gelfand, 2010). In this scenario, the stimulus is controlled by the individual, rather than the audiologist, and is varied continuously. The level is adjusted downward until it is just inaudible and then increased until it is barely audible (Gelfand, 2010). Threshold is determined by taking the mean of the inaudible and audible levels. This method incorporates both ascending and descending approaches to obtain threshold levels.

Byrne et al. (2016) reported the use of the method of adjustment in the HPD Well-Fit device. In comparison to the FitCheck Solo from Michael and Associates, which was set up to use Békésy tracking, the HPD Well-Fit measured attenuation to be within 1 to 2 dB of results from the FitCheck Solo.

Study Rationale

Field fit-testing is an essential part of ensuring HPDs are providing adequate attenuation for the wearer exposed to workplace noise. Previous research compared different field testing systems and how well they measured attenuation (Murphy, 2014). Comparison studies attempted to disclose the variability and accuracy of each system. Byrne et al. (2016) found FitCheck and HPD Well-Fit were accurate within 1 to 2 dB of one another. The HPD Well-Fit system uses field REAT, which has proven to be accurate in testing HPDs in research by Byrne et al. (2016). However, the instructions only followed a descending methodology and current research has not been done to address if there is a difference in PAR scores depending on the type of instruction given by the test operator.

CHAPTER III

METHODS

Real-ear attenuation at threshold hearing protector fit-testing was performed on 30 participants utilizing the HPD Well-Fit (NIOSH, 1996) system with three instruction conditions: descending, ascending, and Békésy (up and down). Personal attenuation rating scores were obtained and recorded for each of the experimental conditions for each research participant. This study was conducted in compliance with an approved research protocol from the Institutional Review Board (IRB) at the University of Northern Colorado (see Appendix A).

Research Participants

Participants, all above the age of 18, were recruited for the study through the use of social media posts, flyers placed in public areas, and emails. Participants did not have previous training in hearing threshold testing. Participants were English speaking and had normal otoscopic findings. The outer ears, including pinna and ear canals, were examined for abnormalities and excessive cerumen. The tympanic membranes were examined for overall health. All participants had hearing thresholds better than 40 dB HL. A pure-tone screening was performed to check thresholds at 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. Participants who had any external auditory canal abnormalities were excluded from the study as well as those who did not pass the pure-tone screening at any frequency. Participants were able to tolerate wearing headphones as well as foam earplugs. In addition, participants needed the physical dexterity and ability to scroll the wheel of a mouse as well as click the mouse button. They also had the ability to read and comprehend written test instructions. Participants signed a consent form prior to the start of the testing (see Appendix B).

Test Environment

Testing was conducted in a double-walled sound-treated booth that met ANSI (2013) guidelines for permissible ambient noise. Participants were seated across from the tester without a view of the computer screen.

Hearing Screening

The initial hearing screening for study inclusion purposes took place in a sound-treated booth with the participant wearing TDH 49 supra-aural headphones. An audiometer placed outside the sound-treated booth was used to screen the test frequencies of 125, 250, 500, 1000, 2000, 4000, and 8000 Hz with pulsed pure-tone stimuli at 40 dB HL. Participants were instructed to press a response button if they heard the stimulus in the test ear. Participants who responded to the stimulus at all frequencies continued with the hearing protection fit-testing.

Hearing Protection

Each participant was fit with a 3M (2019) E-A-R Classic foam earplug by the researcher for occluded conditions. These formable earplugs have a laboratory NRR of 29. To ensure a proper fit was obtained, all participants had a minimum PAR score of 10 on the initial fit-test.

Hearing Protection Device Fit-Testing

Thresholds and PAR scores were obtained using the HPD Well-Fit (NIOSH, 1996) software on a PC laptop. High-output, circumaural TungTech DD52 earphones calibrated to ANSI (2004) standards were utilized during threshold and attenuation testing. Thresholds were determined using pulsed narrowband stimuli. The PAR scores were calculated using the following formula;

$$PAR_7 = L_A - L_{A\text{-}Atten}$$

PAR_7 represents the seven chosen test frequencies, L_A is the A-weighted noise, and $L_{A\text{-}Atten}$ is the measured attenuation subtracted from the A-weighted noise. Each participant had one ear tested. Left and right ears were counterbalanced between participants as well as counterbalanced for the occluded versus unoccluded start condition. Participants responded to the stimuli by adjusting the stimulus level using the scroll wheel of a mouse and clicking the left button to register a threshold. Hearing thresholds were found by averaging the three responses of the participant for the following frequencies: 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. Each frequency required a minimum of three trials and the threshold was taken as the mean of the trials as long as they were within 3 dB of one another. If not, the system would present additional trials until three thresholds were measured within 3 dB of one another.

Test Instructions

Participants were given printed instructions for each of the three experimental conditions (descending, ascending and Békésy). The following instructions were printed individually on plain white paper:

> Descending Instructions: You will hear a series of pulsing sounds through the headphones. Use the scroll wheel of the mouse to make the sounds louder or softer. When you have adjusted the level to the point where you **can just barely**

hear the pulsing sounds, click the left mouse button to move on to the next series of pulsed sounds.

Ascending Instructions: You will hear a series of pulsing sounds through the headphones. Use the scroll wheel of the mouse to make the sounds louder or softer. Scroll down until you can no longer hear the pulsing sounds, then slowly scroll up until you **can just barely hear** the pulsing sounds. When you have adjusted the level to the point where you **can just barely hear** the pulsing sounds, click the left mouse button to move on to the next series of sounds.

Békésy (Up and Down) Instructions: You will hear a series of pulsing sounds through the headphones. Use the scroll wheel of the mouse to make the sounds louder or softer. You will be alternating the sounds to just above and just below what you are able to hear. Scroll down until you can no longer hear the sounds, then slowly scroll up until you **can just barely hear** the pulsing sounds. Repeat this process two more times. When the level is where you **can just barely hear** the pulsing sounds, click the left mouse button to move on to the next series of sounds.

Following each set of instructions, the participants responded to the stimuli as described above. The researcher observed the participants' behavior and screen-tracking on the HPD Well-Fit software. The presentation order of instructions was counterbalanced to avoid the learning effect.

Data Collection

Occluded and unoccluded thresholds as well as PAR scores were determined and stored within the computer software. All PAR scores were exported from the software into a Microsoft Excel spreadsheet for further analysis.

Data Analysis

Personal attenuation rating scores were compared using repeated measures analysis of variance (rANOVA). This statistical model analyzed the means between groups of data. Analysis of variance compared PAR scores between types of instructions and measured any significant difference in the means. The second analysis utilized the Student *t*-test to compare the first PAR score from the first set of instructions to the PAR score from the third set of instructions. The purpose of this analysis was to determine if there was a learning effect that occurred between the first and third test. Learning effects might occur when a participant's score improves due to practice and increased understanding of the task. Statistical analysis was completed using the IBM SPSS statistics software (Version 25).

CHAPTER IV

RESULTS

Study Participants

Thirty adults between the ages of 19 and 68 years were recruited through the use of flyers, social media posts, and university-based subject recruitment websites. All subjects passed the hearing screening and met study inclusion/exclusion criteria. One subject was subsequently excluded from analysis due to lack of responses to four test frequencies despite passing the hearing threshold screening. The mean age of the remaining 29 participants was 31.07 years. Of these, 20 (68.96%) were females and nine (31.04%) were males.

All participants obtained a PAR score of at least 10 during the initial test so there was no need for the researcher to refit any of the earplugs more than once. In addition, there was no need to reinstruct any of the participants regarding fit-testing threshold finding instruction.

Fit-Testing

Appendix C provides PAR score statistics for each participant in all conditions and instruction methods. The descriptive distribution of PAR scores for each instruction method is summarized in Table 3. The PAR score ranges (23 to 23.5) were similar across instruction methods and standard deviations were also similar (6.1 to 6.9). The means of the PAR scores varied by less than .5 dB. The Békésy method showed the greatest range of PAR scores (14.7 to 37.7).

Table 3

Mean Personal Attenuation Rating Scores by Instruction Method

Instruction Method	Minimum	Maximum	Range	Mean PAR	*SD*
Ascending	15.0	35.5	20.5	23.0	6.3
Descending	14.7	35.6	20.9	23.0	6.1
Békésy	14.7	37.7	23	23.5	6.9

Instruction Method Personal Attenuation Rating Comparison

The first research question in this study addressed whether there would be a difference in PAR scores when different sets of instructions were given during fit-testing with the HPD Well-Fit (NIOSH, 1996) system. A one-way rANOVA indicated no significant difference between PAR scores based on instruction method ($F = 2.46286$, $p = .09$) and is summarized in Table 4.

Table 4

Results of One-way Repeated Measures Analysis of Variance

	df	*F*	Significance
Instruction Method	2	2.46286	.094373

$p \geq .05$

Learning Effect on Personal Attenuation Rating Scores

The second research question in this study asked whether a learning effect might influence outcomes when comparing the first and third PAR scores of each participant.

Personal attenuation rating score differences between the first and third tests ranged from 0.2 to 6.7. The order of instructions was counterbalanced and comparison of the mean PAR scores between the first and third instruction set showed 41.38% (*n* = 12) of participants had a decrease in the PAR score from the first set of instructions to the third, meaning the third test score demonstrated greater attenuation as compared to the first test. The remaining 17 participants (58.62%) had an increase in the PAR score from the first set of instructions to the third. Figure 1 demonstrates the distribution of increases and decreases of PAR scores across all participants. All participants with the exception of one had less than a 3.8 difference between the first and third PAR score. One participant had a PAR score increase of 6.7 for the third test.

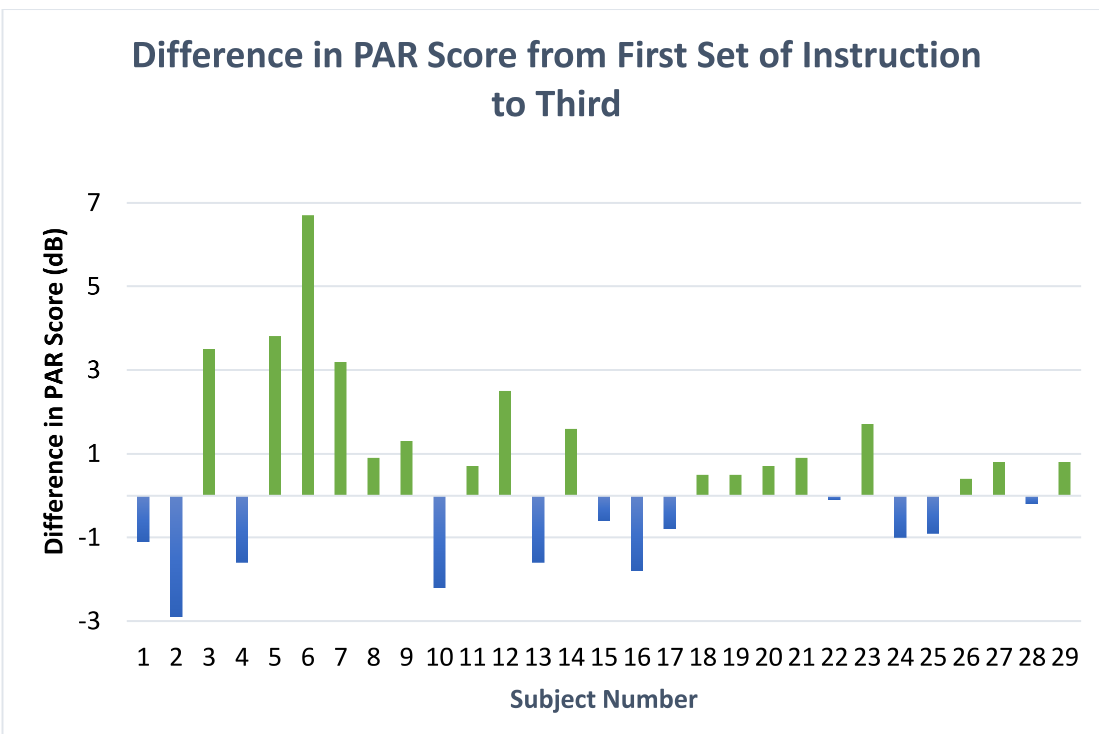

Figure 1. Difference in personal attenuation rating score from first to third instruction set (Initial personal attenuation rating score – Third personal attenuation rating score).

The Student's *t*-test was applied to the first and third PAR scores to determine if a learning effect was observed. A *p*-value of 0.7410 was calculated from the results and t = 0.3322. No statistically significant difference was found between the first and third PAR scores when using an alpha of .05. Therefore, a learning effect was not a factor in this study. Table 5 provides the results from the Student's *t*-test.

Table 5

Results of Student's t-Test When Comparing Personal Attenuation Rating Scores from First Fit-Test to Personal Attenuation Rating Scores Obtained from the Third Fit-Test

	M	*SD*	95% Confidence Interval	*t*
First PAR	22.693	6.154		
			-3.758 to 2.689	
Third PAR	23.228	6.100		0.3322

N = 29

Subjective Feedback

None of the subjects in this study required re-instruction during testing. Informal post-data collection questions included asking participants which instruction method was easiest to understand. The consensus among participants was the ascending and descending methods were easiest to understand and follow. No participants stated Békésy was a preferred method of instruction. Several said it was difficult to keep track of how many "up-and-down" sequences they had done before pressing the mouse button. The length of time required for testing was not recorded in this study; however, several participants stated after testing that the Békésy method took too long.

Summary

These results indicated no significant difference in PAR scores was measured from 125 to 8000 Hz when using written ascending, descending, or Békésy instruction methods. A learning effect was not evident across a series of three PAR measurements when the researcher fit the 3M E-A-R Classic hearing protector to the ear.

CHAPTER V

DISCUSSION

The purpose of this study was to determine if differences in written test instructions would alter PAR scores among individuals evaluated with the NIOSH (1996) HPD Well-Fit hearing protector fit-testing system. Topics addressed in this section include field versus laboratory attenuation comparison, experimenter fit, instruction recommendations, and application of PAR scores in the workplace.

Field Versus Laboratory Attenuation Comparison

The manufacturer labeled NRR for the 3M (2019) E-A-R Classic earplugs used in this study was 29, which was the statistical measurement that predicted the amount of attenuation achieved by an estimated 84% of the population. As stated earlier, the NRR does not provide a real-world measurement of earplug attenuation and actual attenuation scores vary greatly when measured in the field (Murphy et al., 2016). Smith, Monaco, and Lusk (2015) used f-MIRE to measure attenuation and obtain a PAR score for workers in a metal can manufacturing plant. Of the 327 participants, they found 28% were not reaching high enough attenuation levels to be protected from noise exposure. This level was determined by taking a baseline PAR measurement and comparing it to the target minimum attenuation. The minimum attenuation was calculated by subtracting the employee's exposure limit from the company's exposure limit (Smith et al., 2015). Berger et al. (1996) performed an in-depth analysis of hearing protector attenuation field studies and how well they related to NRR labeling on hearing protector packaging. This research revealed the NRR was accurate 84% of the time in field studies compared to 98% of laboratory subjects (Berger et al., 1996). In the current study, 100% of the participants met the minimum PAR score of 10 set forth by the researcher but only 19.5% of the PAR scores equaled or surpassed the 29 dB NRR from the manufacturer in spite of being fit by the researcher. This outcome was likely due to the fact that the purpose of the experiment was not achieving maximal attenuation during fitting but reaching the desired minimum PAR score. Trompette, Kusy, and Ducourneau (2015) compared hearing protector performance using REAT through three commercially available systems: the VeriPRO by Honeywell, EARfit by 3M, and CAPA by Cotral to MIRE benchmark results. They found attenuation for the 3M E-A-R Classic earplug and other pre-molded earplugs was not statistically different on average for a 95% confidence interval (Trompette et al., 2015). The measured performance of the 3M E-A-R Classic earplugs in the Trompette et al. study indicated the REAT method was comparable to the MIRE method when completing fit-testing with these earplugs.

Table 6 provides a comparison of studies utilizing the 3M (2019) E-A-R Classic earplug and measured attenuation values. Within the table, the measurement approach delineates whether the REAT or MIRE method was used by the researchers and the setting describes if the study was performed in the laboratory or in the field. The fitter column indicates if the HPD was fit by the researcher or by the subject. Attenuation values show either the exact value or range measured by the researchers. Franks, Murphy, Johnson, and Harris (2000) compared experimenter fit attenuation to subject fit. Both measurements were below the labeled NRR of 29 for the 3M E-A-R Classic earplugs. Neitzel, Somers, and Seixas (2006) used both REAT and MIRE measurement methods to compare the 3M plugs to custom molded plugs. Values for the custom molded plugs are not listed but had higher attenuation values than the foam earplugs. Murphy, Stephenson, Byrne, Witt, and Duran (2011) analyzed how different training sequences influenced attenuation scores. All HPDs were fit by the subject in this study and attenuation was measured three times. Subjects were either given a video instruction first and then written instructions, or vice versa. The third measurement was always taken after the subjects were given expert fitting instructions from the researcher. Pääkkönen, Lehtomäki, Myllyniemi, Hämäläinen, and Savolainen (2000) utilized the MIRE method to compare the 3M E-A-R Classic attenuation levels alone to ear muff attenuation and a combination of both plugs and muffs.

Table 6

Comparison of Attenuation Between Studies Utilizing 3M E-A-R Classic Earplugs

Citation	Measurement Approach	Setting	Fitter	Attenuation PAR Score
Franks et al. (2000)	REAT	Laboratory	Experimenter	27.0
Franks et al. (2000)	REAT	Laboratory	Subject	17.0
Neitzel et al. (2006)	MIRE	Field	Experimenter	14.9
Neitzel et al. (2006)	REAT	Field	Experimenter	20.4
Murphy et al. (2011)	REAT	Laboratory	Subject	23.3 – 41.6
Pääkkönen et al. (2000)	MIRE	Laboratory	Experimenter	28.0 – 31.0

The mean attenuation score in the current study ranged from 23 to 23.5. For previous studies, the variation in attenuation scores shown in Table 6 for subject fit ranged from 17 to 41.6 while experimenter fit ranged from 14.9 to 31. As stated earlier, the purpose of this study was not to maximize HPD attenuation fitting but the PAR scores obtained in the current study were similar to those reported in previous studies.

Experimenter Fit

The outcomes of this study reflected the earplug fitting by a single experimenter and are not representative of how earplugs would be fit by individual wearers in the field. Research has shown proper training on HPD insertion for users is essential for ensuring maximum protection (Gong, Liu, Liu, & Li, 2019; Samelli, Rocha, Theodósio, Moreira, & Neves-Lobo, 2015). Samelli et al. (2015) compared PAR scores achieved by 40 individuals who had training on proper insertion of HPDs to 40 individuals in a control group that received no training. The control group not only had significantly lower levels of attenuation than the group that received instructions but also had lower attenuation values than those provided on the manufacturer packaging. Gong et al. (2019) also assessed the efficacy of training for HPD use. After performing initial fit-testing on factory workers from four sites, those who did not reach optimal PAR scores were reinstructed on fitting and then re-tested. Significant improvement was seen in PAR scores both post-intervention and at follow-up fit-testing several months later for two of the four factories (Gong et al., 2019). Proper education in the use of HPDs helps to improve attenuation and hearing protection effectiveness. It might be useful to repeat this study with earplugs that were self-fit because the actual PAR scores would likely differ from those obtained with experimenter fit earplugs. However, the outcomes related to instruction wording would be expected to be the same as the current study since selffitting an earplug would not influence how the wearer responds to the stimuli during HPD Well-Fit (NIOSH, 1996) threshold testing.

Instruction Recommendations

Since no significant difference in PAR scores was measured between test instructions, any of the three methods used in this study would be appropriate for testing. Previous research conducted by Tyler and Wood (1980) analyzed differences in hearing threshold measurement as a result of differing test instructions including a descending method and the ASHA proposed Hughson-Westlake method (ascending). Their results indicated no significant differences were found in thresholds when comparing these two instruction methods. The research performed in this study further supported that each of these methods produced a similar estimate of threshold. Dancer et al. (1976) similarly found estimated thresholds were not influenced by instructions or by encouraging subjects to guess if they were not sure if they heard the stimulus. Byrne et al. (2016) compared thresholds obtained through the method of adjustment and Békésy tracking using fit-testing systems. The results indicated a 1 to 2 dB difference between the methods in that research study, which was in agreement with the .5 dB difference in PAR scores for the current study.

After considering informal feedback from subjects and test time approximations, using the ascending or descending methods might be the most time-efficient choices. Test-takers might be less fatigued with shorter testing time and more straightforward instructions. The ascending method might be more accurate than the descending method as it requires more careful attention from the participant in terms of motor control. It is possible for those who follow the descending method to scroll the wheel of the mouse too far past their threshold depending on the smoothness of the tracking wheel mechanism, which might result in an inaccurate PAR score. This is why careful instruction phrasing is used to ensure they only scroll just below their threshold.

Tyler and Wood (1980) stated the instructions given need to be simple to understand for both the subject and the tester to avoid false responses. To ensure consistency over time with written instructions, it is important for those administering the test to always refer to the written instructions and avoid verbally giving instructions. Differences in verbal instructions might contribute to skewed results and inaccurate data collection.

With regard to instructions, Johnson, Sandford, and Tyndall (2003) found recall and understanding were greater in subjects who were given written and verbal instructions before a hospital discharge compared to those given just verbal instructions. The use of written instructions in fit-testing would allow the researcher to use any method of instruction they preferred and PAR scores would not be expected to change between researchers and methods of instruction.

Workers familiar with fit-testing in the workplace might be accustomed to using the Hughson-Westlake model put forth by ASHA (2005), which is an ascending approach. It is important to consider that some workers might be used to this method of instruction and if a new method was implemented, the researcher must ensure the instructions are understood prior to testing being completed.

Personal Attenuation Rating Measurements in the Workplace

There was no evidence of a learning effect between the first set and third set of instructions. Since the HPD was not removed between method of instructions, it is unlikely the PAR scores changed as a function of fit. When testing multiple PAR scores (greater than three) using different HPDs in the workplace, it might be important to rule out a learning effect that might possibly occur later in time. Byrne et al. (2016) postulated a trial frequency would be beneficial when using the HPD Well-Fit (NIOSH, 1996) system. This might be achieved by testing a trial frequency at the beginning of the session to ensure the participant understands the instructions without recording these results. The trial frequency would then be tested again later in the session and those results would be used in analysis. This approach was not evaluated in the present study but might be useful regardless of the instruction type.

Study Limitations

One major limitation of this study was the small sample size ($N = 29$). More participants would be needed to obtain a large-scale analysis of the differences between test instructions. However, the mean differences were minimal (0.5 dB) and the standard deviation (6-7 dB) was similar to that for hearing threshold testing (±5 dB; Stuart et al., 1991). No information was obtained on how effective these instruction methods would be for individuals with hearing loss greater than 40 dBnHL and/or tinnitus or those who are not native English speakers if instructions were translated.

Future Research

The results from this study applied to research and clinical practice related to performing hearing protector fit-testing and the prevention of NIHL in high noise level work settings. Valuable information regarding test instructions has been established specific to the NIOSH (1996) HPD Well-Fit system. The following factors should be considered in future research: (a) consider whether the results would differ if the participants self-fit the HPDs, (b) expand the study to evaluate PAR scores using custom-hearing protection or other types of HPDs, (c) evaluate these test instructions with other fit-testing systems that utilize the method of adjustment to obtain PAR scores, and (d) evaluate subjects that represent a more diverse workforce including those with hearing loss greater than 40 dBnHL or tinnitus or non-native English speakers. These questions would serve the purpose of furthering knowledge regarding fit-testing performance.

Conclusion

The results of this study suggested any of the three test instruction types (ascending, descending, or Békésy) would be sufficient to use in the field with the NIOSH (1996) HPD Well-Fit system. The difference between PAR scores (.5 dB) was not significant and, therefore, it would be appropriate to select any of the test instruction sets to use. Although this study was completed in a research setting, the HPD Well-Fit has many applications in the industrial field setting. The implementation of written instructions was expected to be the same in the field as in the laboratory setting. For workers enrolled in a hearing conservation program, the ascending threshold approach might be most familiar and time efficient.

Hearing conservation is an important goal for not only hearing conservationists but audiologists and health care professionals as it works to encourage continued hearing health for individuals. Regulations in the workplace put forward by organizations such as OSHA and guidelines suggested by NIOSH (1996) established important standards for minimizing the risk of NIHL in workers. In workplaces, maximal effectiveness of HPDs is the secondary goal after noise control as the primary approach to hearing loss prevention. Using poorly fit HPDs and being under-protected increases risk of NIHL and being over-protected might interfere with workplace safety and performance. Hearing protector fit-testing facilitates the determination of the appropriate balance between sufficient attenuation to minimize the risk of NIHL and the maximum attenuation permitted before overprotection jeopardizes worker safety and communication. The results from this study supported the practical implementation of HPD fit-testing in the field and emphasized the ease of verifying HPD effectiveness. By using standardized test instructions, researchers and field examiners will achieve comparable PAR scores when testing with the NIOSH HPD Well-Fit system.

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APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL

UNIVERSITY OF
NORTHERN COLORADO

Institutional Review Board

DATE:	July 17, 2018
TO:	Katherine Steffen, B.A.
FROM:	University of Northern Colorado (UNCO) IRB
PROJECT TITLE:	[1187396-1] Effects of Written Instructions on Field Real Ear Attenuation at Threshold Measurement
SUBMISSION TYPE:	New Project
ACTION:	APPROVED
APPROVAL DATE:	July 17, 2018
EXPIRATION DATE:	July 17, 2019
REVIEW TYPE:	Expedited Review

Thank you for your submission of New Project materials for this project. The University of Northern Colorado (UNCO) IRB has APPROVED your submission. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on applicable federal regulations.

APPENDIX B

CONSENT FORM FOR HUMAN PARTICIPANTS IN RESEARCH

UNIVERSITY of NORTHERN COLORADO

CONSENT FORM FOR HUMAN PARTICIPANTS IN RESEARCH
UNIVERSITY OF NORTHERN COLORADO

Project Title: Effects of Written Instructions on Field Real Ear Attenuation at Threshold Measurements
Researcher: Katherine Steffen, B.A, School of Human Sciences
E-mail: stef3774@bears.unco.edu
Research Advisor: Deanna Meinke, Ph.D, School of Human Sciences
Research Advisor E-mail: deanna.meinke@unco.edu

Purpose and Description: The primary purpose of this study will be to determine the most appropriate method of instructions to use when performing hearing protector effectiveness tests. This research will require one visit with the researcher. During the visit, you will be evaluated for healthy ear function using an ear flashlight. We will also perform a quick hearing screening to ensure hearing thresholds will not exceed the outputs of the test headphones. Then, you will be fit with foam hearing protection and computerized hearing test measurements will be taken to evaluate the effectiveness of different testing instructions. The effectiveness will be determined by having you listen to tones with and without the earplugs in your ears. The earplugs will be yours to keep after the study. The goal of this study is to determine if one method of instruction yields better attenuation scores.

For the visit, I will use an ear flashlight to look in your ear to make sure there is no evidence of blocked or abnormal ear canals. If not, I will perform a hearing screening to check specific frequencies. I will place headphones on your ears and ask you to listen for specific tones. When you hear the tones, you will respond by pressing a button. If you respond at a predetermined level at all frequencies, I will proceed with computerized hearing testing. I will give you some printed instructions and you will be asked to read through them and use those instructions to perform the hearing testing. I will give you three different sets of instructions. I will then place an earplug in your ear and perform the testing three more times for a total of 6 hearing tests.

At the end of the experiment, we would be happy to explain what we learned from the testing. We will take every precaution in order to protect your anonymity. We will assign a subject number to you. Only the principal investigator and her research advisor will know the name connected with a subject number and when we report data, your name will not be used. Consent forms and the linkage between the subject number and name will be destroyed after the second visit and will be stored separately in a locked file cabinet in our research lab between visits. De-identified data collected and analyzed for this study will also be kept in a locked cabinet and summary data will be stored on a personal password protected computer.

The potential risks to you are no greater than when a person comes in to see an audiologist for a routine audiological evaluation, or when having your hearing tested in the workplace. Potential minor risks associated with this study include ear canal redness and slight discomfort. Additional more severe risks are possible, but rarely occur. These include: creating a sore in the ear canal, slight pain when removing the earplug. Any of these more severe outcomes that would necessitate that you see your personal physician or a medical ear specialist. The student researcher and the faculty research advisor are well trained and experienced in performing these tasks and will work to minimize any of these potential risks from occurring.

Upon completion of the research study, you will be permitted to keep the pair of foam earplugs that were used in the testing. If worn when exposed to hazardous sound levels, your hearing will be better protected

from the risk of noise-induced hearing loss. Employers and workers wearing hearing protectors will be the populations who most benefit from the results of this study.
Participation is voluntary. You may decide not to participate in this study and if you begin participation you may still decide to stop and withdraw at any time. Your decision will be respected and will not result in loss of benefits to which you are otherwise entitled. Having read the above and having had an opportunity to ask any questions, please sign below if you would like to participate in this research. A copy of this form will be given to you to retain for future reference. If you have any concerns about your selection or treatment as a research participant, please contact the Office of Research, Kepner Hall, University of Northern Colorado Greeley, CO 80639; 970-351-1910.

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Subject's Signature Date

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Researcher's Signature Date

APPENDIX C

PERSONAL ATTENUATION RATING SCORES BY SUBJECT

Method			
Subject	Ascending	Descending	Békésy
101	25.8	26.3	24.7
103	30.5	33.4	33.4
104	31.8	28.3	37.7
105	33.5	32.2	33.8
106	26.5	25.0	21.2
107	19.2	23.8	25.9
108	23.1	26.0	26.3
109	19.3	18.6	19.5
110	32.2	30.9	33.4
111	26.0	24.5	26.7
112	35.5	35.6	34.9
113	17.0	17.8	19.5
114	23.9	25.6	22.3
115	34.9	33.3	34.6
116	27.3	27.9	27.5
117	19.4	18.7	20.5
118	21.4	19.8	20.6
119	21.7	20.6	22.2
120	18.9	17.4	19.4
121	19.6	18.9	16.8
122	19.4	18.5	19.5
123	16.4	17.4	17.5
124	15.0	17.0	15.3
125	17.7	17.6	16.7
126	16.7	15.5	15.8
127	25.6	26.0	26.0
128	15.5	14.7	14.7
129	15.5	15.7	15.2
130	17.8	20.4	18.6