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Christie De Vito
University of Iowa

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COMPARISON OF PERSONAL ATTENUATION RATINGS ATTAINED BY AGRICULTURAL AND INDUSTRIAL WORKERS FOR FOUR HEARING PROTECTION TYPES USING THE 3M E-A-RFIT DUAL VALIDATION SYSTEM

by

Christie De Vito

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of the requirements for the Master of Science
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Thesis Supervisor: Associate Professor T. Renee Anthony

Graduate College
The University of Iowa
Iowa City, Iowa

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

Christie De Vito

has been approved by the Examining Committee for
the thesis requirement for the Master of Science degree
in Occupational and Environmental Health at the May 2017 graduation.

Thesis Committee:

T. Renee Anthony, Thesis Supervisor

Matthew Nonnenmann

Anne Skinstad

To my parents and my family for always supporting me throughout my academic career and for encouraging me to focus on my school work and future career.

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ABSTRACT

Despite the enactment of hearing protection laws and recommended standards over the last four decades, the prevalence of hearing loss among workers has remained unchanged. Limiting the amount of time spent in high noise areas, as well as wearing hearing protection devices, can reduce the effects of noise on hearing loss. Though research has examined the consistency of use of hearing protection devices (HPD) among workers, the importance of fit, and a real-world comparison to the marketed attenuation needed further examination.

The goal of this project is to evaluate the effectiveness of HPDs used by agricultural and industrial workers enrolled in a hearing conservation program by comparing personal attenuation rating (PAR) to the manufacturer's reported noise reduction rating (NRR). The two study groups were selected since workplaces are required to train workers enrolled in an OSHA Hearing Conservation Program on proper insertion techniques, but farmers do not typically receive any training on using hearing protection unless they are employed elsewhere. The effectiveness of the inserted HPDs were quantified via the 3M E-A-Rfit^{TM} Dual Ear Validation System, and the results were compared to the NRR provided by the manufacturer. The fit of hearing protection was evaluated for 60 farmers (247 plug pairs) and 76 workers (275 plug pairs), using four models of earplugs (two formable and two non-formable). The results show that although formable ear plugs have higher reported NRRs, a higher percentage of participants achieved PARs greater than or equal to the A-weighted adjusted NRR-7 for the non-formable plugs.

PUBLIC ABSTRACT

Hearing protection devices (HPD) are encouraged to be worn to reduce exposure to noise sources when elimination and engineering controls are not feasible. However, research on the fit of HPD and the ability of the HPD to achieve attenuation ratings comparable to the manufacturer’s noise reduction ratings (NRR) is limited.

This project examined the fit of HPD on agricultural and industrial workers by quantifying personal attenuation ratings (PAR) for four different types of HPD (two formable and two non-formable) via the 3M E-A-Rfit^{TM} Dual Ear Validation System.

The results of this project have found that more participants could achieve PARs greater than or equal to the A-weighted adjusted NRR-7 using non-formable HPD compared to formable HPD.

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Chapter 1

Literature Review

Standards and Definitions

Sources of noise and sound are universally prevalent. Sound is a sensation in the ear canal resulting from the oscillation of stress, pressure, and particle velocity or displacement in a medium with elastic or viscous forces (ANSI/ASA S11-2013). Noise is any unwanted sound created from the oscillations (NIOSH, 1998). Noise can be described as either impact, intermittent, or continuous. Impact or impulse noise can be described as a sudden increase in the sound level, such as the sound resulting from a hammer suddenly hitting a nail head or a balloon pop. Continuous noise is noise that occurs for a steady period. Intermittent noise is when the noise has periods of stopping and restarting again.

Sound levels measure vibrations that move through the environment. Sound can be described by the magnitude of pressure change associated with the vibrations, or the frequency (the cycles per second) of the vibrations. The unit of measurements for the pressure changes associated with vibrations is the decibel (dB) (NIOSH, 1998). Frequency is defined as the number of times per second that the sound vibration completes a cycle of motion and is measured in Hertz (Hz). Most humans can hear sounds between 20 Hz and 20,000 Hz, though human hearing is most sensitive to the frequencies of human speech, between 2000-5000 Hz (Plog, 2002). An octave band is named by its center (geometric mean) frequency and describes the range of frequencies starting at a frequency and extending to double that frequency. There are nine octave bands. The most commonly used octave bands are 31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000 Hz.

When measuring sound levels to assess human exposures, it is common to aggregate sound levels across the entire range of hearing frequencies to arrive at a single weighted sound level. Three weighting scales are commonly used. All frequency weighting schemes are set to zero adjustment at 1000 Hz. The A-weighted scale is commonly applied to assessments of occupational hearing measurements, as it is adjusting the sound level to simulate the differences in people's perception of noise across the range of hearing frequencies. For example, a sound level of 64 dB at 1000 Hz is perceived as a similar sound level of 80 dB at 125 Hz, since the A-weighted scale reduces the measurements in the 125 Hz range by 16.1 dB.   The C-weighted scale has smaller adjustments to frequency-specific sound levels compared to the A-weightings. For example, a sound level of 64 dB at 1000 Hz is perceived as a similar sound level of 64.2 dB at 125 Hz since the C-weighted scale reduces the measurements in the 125 Hz range by 0.2 dB.   C-weighted sound measurements are commonly used in engineering investigations and to calculate the noise reduction rating (NRR) of hearing protection devices (HPD) (NIOSH,1998).   The Z-weighing scale is a flat weighting that is often used with octave band analyzers to measure sounds across the frequency spectrums (United States, Occupational Safety and Health Administration).

There are different instruments to measure sound sources. A sound level meter is used for area surveys, or to determine personal noise exposure at a fixed location. A noise dosimeter is worn by a worker to measure personal noise exposure levels over a period. The meters report the sound pressure level (SPL) in dB or dBA. An octave band analyzer measures sound levels across frequency bands relevant to human hearing to provide an overall sound level.

All exposure limits require monitoring to be conducted using either a Type I or Type II sound level meter. A Type I sound level meter has an accuracy of +/- 1 dB, while a Type II sound level meter has an accuracy of +/- 2 dB. The meter can be set to either fast or slow response. A slow response provides an average of the sound level measured over 1 second, while the fast response follows quickly changing sound levels over periods of 125 milliseconds (Anna, 2011). Criterion is the maximum allowable exposed dose set by the exposure limit. The threshold is the level set on a sound level meter at which noise will be captured and calculated as part of the exposure dose; any sound level below the threshold will not be included in the calculation of the measured dose.

In occupational settings, sound level data is used to determine the time-weighted average (TWA) to assess worker exposures, typically over a full shift (8-hours) (NIOSH, 1998). The TWA can then be compared to the recommended exposure limits from multiple standards set to protect worker health. These exposure limits vary in criterion and threshold. The Occupational Safety and Health Administration (OSHA) established the permissible exposure limit (PEL) described in 29 CFR 1910.95. Per OSHA, the PEL for an eight-hour work shift is 90 dBA (criterion) as measured by a Type II, slow response, sound level meter that uses a 5-dB exchange rate and includes all sound levels at and above 90 dB (threshold for engineering controls). An exchange rate of 5 dB means that for every 5 dB increase in sound level, the duration of allowable exposure is divided in half (United States, Occupational Safety and Health Administration). The OSHA Hearing Conservation Standard requires employees that are exposed to 85 dBA, at 5 dB exchange rate with an 80 dB threshold to be enrolled in a Hearing Conservation Program. The Hearing Conservation Program requires employees to receive baseline and annual audiometric testing. Employees are to receive annual training on noise and hearing protection. HPD (one ear plug option and one ear muff option) are to be given to employees working in areas exceeding the 85 dBA TWA action level (United States, Occupational Safety and Health Administration). The American Conference of Governmental Industrial Hygienists (ACGIH) recommends a threshold limit value (TLV) for an eight-hour work shift of 85 dBA with a 3 dBA exchange rate (ACGIH, 2014). The National Institute of Occupational Safety and Health (NIOSH) recommends similar noise exposure limits, with the 8-hour recommended exposure limit (REL) as 85 dBA with a 3 dBA exchange rate.

When exposures to sound changes throughout the day, exposure data must be processed to assess whether workers are at risk of noise induced hearing loss. To do this, the allowed duration of exposure at specific sound levels must be computed, and then a daily dose is calculated. From the dose, the time-weighted average is computed, allowing comparisons to the exposure limits mentioned above in the OSHA and NIOSH/ACGIH recommended noise standards. The allowable exposure duration for the measured SPL can be calculated for either standard using the full-shift length time and the measured SPL using the sound level meters.

$$Time\ Allowed\ (minutes) = \frac{480\ (minutes)}{2^{\frac{SPL\ (dBA) - Exposure\ Limit}{Exchange\ Rate}}}$$

Dose is the percent exposure time relative to the allowable exposure time at a specified SPL and is represented as a percentage of the allowable exposure. The TWA can then be calculated using the calculated noise dose. There are two different equations to calculate the TWA depending on the standard to be followed.

$$Dose(\%) = (\sum_{n} \frac{Time\ of\ exposure\ at\ noise\ level\ n}{Time\ Allowed\ at\ noise\ level\ n})*100$$

$$OSHA\ TWA\ (dBA) = 16.61 * (\log Dose\%) + 90$$

$$NIOSH/ACGIH\ TWA\ (dBA) = 10.0 * (\log Dose\%/100) + 85$$

The calculated TWA can then be compared to the exposure limits set by OSHA and ACGIH/NIOSH to determine if further controls need to be identified to reduce noise exposure and to prevent hearing loss.

Anatomy of the Ear and Hearing Loss

Sound is transferred via the human ear. The ear transforms external sound waves into stimuli detected by the nervous system and transmitted to the brain. This transmittance of the sound waves helps the body know its position relative to the external environment. The anatomy of the ear is discussed as three parts: the outer/external, middle, and inner/internal ear. The external ear collects sound waves via the acoustic canal and transports them to the tympanum located in the middle ear. The middle ear communicates the sound waves using the interaction between the mastoid apparatus and tympanic cavity. Three ossicles (small bones), malleus, incus, and stirrup, along with the auditory (Eustachian) tube, pharynx, and tympanic membrane comprise the middle ear. Air vibrations operating at different frequencies move the tympanic membrane (ear drum) (Human Anatomy, 2006). The vibrations at the tympanic membrane are transferred through the ossicles, which amplify the vibrations, to the fluid-filled cochlea, which contained the sensory organ for hearing (Lusk, 1997). The cochlear duct is surrounded by the membranous labyrinth which is within the bony labyrinth. The membranous labyrinth is surrounded by perilymph (fluid derived from blood plasma) and filled with endolymph fluid (Hawkins, 2015).

Within the cochlea, there are 15,000-30, 000hair cells (cilia) and nerve fibers that respond to sound frequencies (Lusk, 1997). Cilia are located on the basilar membrane inside the Organ of Corti and vibrate in response to sound waves. The different frequencies and wavelengths of sound stimulate the basilar membrane. The mass of the Organ of Corti increases from the basal end to the apex, which is opposite of the hair cells. The hair cells located at the basal end are stiffer and shorter than those at the apex which are looser and longer to respond to the frequency range. The ends of the cells are not attached to the membrane but are embedded into the membrane allowing them to vibrate (Hawkins, 2015). The cilia that respond to higher frequency sounds (>6,000 Hz) are more susceptible to damage (Lusk, 1997). As the cilia become damaged from chronic noise exposure, impulse noise, aging, or disease, they begin to degenerate and disappear. The weakened cilia can no longer vibrate in response to the sound as rapidly as before damage. (Hawkins, 2015).

Data from the National Health and Nutritional Examination Surveys for the 2001-2008 cycles found an estimated 12.7% or 30 million Americans over the age of 12 years have bilateral hearing loss (both ears), and an estimated 20.3% or 48.1 million Americans over the age of 12 years have unilateral hearing loss (one ear) (Lin, et al, 2011). Noise Induced Hearing Loss (NIHL) occurs when structures in the inner ear are damaged after exposure to noise (Human Anatomy, 2006). NIHL often starts out as a loss of hearing in the higher frequency ranges for human speech (Von Essen and McCurdy, 1998). A threshold shift or a change in the auditory threshold detected by audiometric testing, occurs when there is a reduction in hearing capabilities. The shift can either be temporary, which often occurs daily over the period of a shift or permanent (Human Anatomy, 2006). A standard threshold shift (STS) is defined by NIOSH as an increase in the hearing threshold level in either ear by 15 or more dB at any frequency (500, 1000, 2000, 3000, 4000, 6000 Hertz) (NIOSH, 1998). OSHA describes an STS as an increase in threshold compared to the baseline audiogram by an average of 10 dB or more at 2000, 3000, and 4000 Hz in at least one ear (United States, Occupational Safety and Health Administration). Presbycusis is the natural decrease in hearing capabilities that often accounts for hearing loss in the older populations (Human Anatomy, 2006). Tinnitus, or a ringing in the ear, is commonly felt by people with hearing loss and considered a moderate annoyance, as the prevalence of tinnitus increases with age and noise exposure (Palmer, 2002). The sound level, sound frequency, duration of exposure, and impulsiveness all contribute hearing loss.

Hearing loss from occupational settings is one of the most common work related illnesses (Masterson, et al, 2016). There are an estimated 30 million people at risk for noise-induced hearing loss from work, recreational activities, and at-home exposures. Workers in the agricultural, construction, mining, utilities, manufacturing, transportation, and military industries are at high risk for exposure to noise (Rogers, et al, 2009). The NIOSH Occupational Hearing Loss Surveillance Project examined audiograms of 1.4 million workers across industries exposed to noise from 2003-2012 and found that 2.5 healthy years of hearing are lost each year per 1000 noise-exposed workers. A study conducted by Masterson, et al, examining 2000-2008 audiograms provided to NIOSH for male and female workers age 18-65 found that 18% of those workers have hearing loss.

The study also found that men were two and half times more likely to have hearing loss compared to women. Hearing loss prevalence increased with age, with those 56-65 years old being 19 times more likely to have hearing loss. An estimated 16.22% of workers in the agricultural, forestry, fishing, and hunting industry, and an estimated of 19.81% in the manufacturing industry have hearing loss from data analyzed in 2000-2008 (Masterson, et al, 2013).

The reported prevalence of hearing loss among farmers differs between studies from 17%-72% (McCullagh, et al, 2016). A study conducted by Plakke and Dare (1992) found that as age increased farmers had a higher occurrence of hearing loss compared to the matched office workers. Farmers that also work in industry may have an even greater risk for hearing loss, since many farming tasks expose farmers to noise at high doses during short periods of time, or lower noise doses over longer periods of time (Plakke and Dare, 1992). Farm animals, equipment and machinery, such as feed grinders, tractors, chain saws, and swine are sources of loud noises often exceeding 90 dB (Von Essen and McCurdy, 1998). In 1998, Von Essen and McCurdy reported that 65% of dairy farmers have hearing loss. There have been documented cases of hearing loss starting in the teenage years (Von Essen and McCurdy, 1998). Young males who work and live on farms have a high prevalence of hearing loss (Ehlers, 2011). An estimated 25% of male farmers have hearing loss by the age of 30, and 50% have hearing loss by the age of 50. An average healthy person typically does not have hearing loss until the age of 60 if they are not exposed to high levels of noise (Ehlers, 2011).

Surveillance and Controls

Hearing loss can be prevented or controlled through medical and workplace monitoring, abatement of noise hazards, and by wearing personal protective equipment.

Medical surveillance via annual audiometric testing will detect early changes in individual hearing when compared to a baseline audiogram. A baseline audiogram at initial hire is recorded for each employee to compare future annual audiograms to (Rogers, et al, 2009). Monitoring of noise sources via area noise surveys and personal noise dosimetry can detect activities associated with high noise exposures. These noise sources can be controlled via engineering controls (noise dampers, revamping of industrial processes, new motors, etc.) or administrative controls (limiting durations of high exposure, moving employees away from sources of high exposure). HPD such as ear plugs or ear muffs, should be used when engineering controls are not sufficient in reducing exposure sources below regulatory limits to protect against hearing loss.

HPD come in different forms: ear muffs with or without communication features, formable ear plugs, and non-formable ear plugs. Ear muffs can be worn over ear plugs when double protection is needed in extremely high noise environments. They are often most useful in dirty environments where rolling down ear plugs would transfer contaminants onto the ear plug and into the ear, or during brief periods of exposure. Ear muffs provide a more uniform fit across users and can be adjusted for head size. Formable ear plugs require the wearer to roll the ear plugs down before inserting them into the ear. Non-formable ear plugs are simply pushed into the ear. Ear plugs may be better suited for longer durations of wear and in hot environments (Canadian Centre for Occupational Health and Safety).

Manufacturers of HPD provide a noise reduction rating (NRR). The Environmental Protection Agency (EPA) proposed a rule in 2009 after advancements in technology have been made for “Product Noise Labeling Hearing Protection Devices” to revise the “Noise Labeling Standards for Hearing Protection” that were enacted in 1979 as part of 40 CFR Part 211. The standards provide testing guidelines for manufacturers of HPD for assessment and labeling purposes. Manufacturers of HPD are required to provide information on the effectiveness of reducing noise levels to the ear via the NRR, and the information must be clearly visible on the label. ANSI S3.19-1974 outlines the testing requirements for HPD and is adopted in the EPA standard. The NRR is the estimated average reduction in dB that the HPD would provide against noise sources. The NRR is based on the average attenuation of ten different people tested three times during experimental lab testing (Federal Register, 2009). However, ANSI S3.19-1974 has been replaced by ANSI/ASA S12.6-2008 which provides data that is more closely related to real world application of use (Federal Register, 2009). ANSI/ASA S12.6-2008 outlines two methods for testing HPD. The first method tests HPD on trained users, while the second method tests HPD on users without experience to mimic users in the workplace (NIOSH Methods). Noise reduction rating determinations are conducted using measurements in the unadjusted dB scale. Therefore, OSHA recommends subtracting 7 dB from the NRR to adjust to the A-weighted scale required for exposure monitoring. OSHA then provides a safety factor by dividing the (NRR-7) value by 2. The derated value is then subtracted from the measured exposure estimate to determine the effective noise exposure for a worker wearing that HPD (United States, Occupational Safety and Health Administration).

$$Effective\ NRR_{OSHA}\ (dBA) = \frac{(NRR - 7)}{2}$$

$$Effective\ Exposure_{OSHA}\ (dBA) = dBA - Effective\ NRR$$

NIOSH has derating recommendations for each specific HPD type to account for error in inserting the HPD, differences in human ears, and material differences. Each HPD type has a different adjustment factor (earmuffs=0.25; formable ear plugs= 0.50; non-formable ear plugs= 0.70). The estimated exposure level after insertion of the HPD is calculated like the OSHA method using the adjustment factors (NIOSH, 1998).

$$Derated\ NRR = NRR - (NRR * adjustment\ factor)$$

$$Estimated\ Exposure\ (dBA) = dBA - (Derated\ NRR - 7)$$

Research based on intervention showed that young farmers who were educated in the prevention of hearing loss were more likely to use hearing protection, and the parents of the young farmers also increased their own usage after their children received the education (Ehlers, 2011). However, many farm family members do not consistently use HPD. Only seven percent of participants in a research study examining the effects of hearing impairment on farm families claimed to wear HPD more than 50 percent of their working time, and ear plugs were the only choice of HPD used. Many farmers feel that HPD decrease their quality of communication and inhibit warning signals (Carruth, et al, 2007).

Education of HPD use during initial orientation of new workers and repeatedly throughout their work time is a requirement of a hearing conservation program. Motivation of HPD use is also important for promoting a safe and healthy work environment. Demonstrations and practice sessions on how to properly insert HPD attempt to ensure HPD are worn properly (Rogers, et al, 2009).

E-A-Rfit Importance

Technology and software for the fit testing of HPD on individuals has been available for 20 years. However, it generally occurred in laboratory settings to obtain representative data on the effectiveness of HPDs to reduce noise exposure levels. Professionals have only recently started applying the technology in workplaces after the realization from laboratory data that the fit of HPD varies between individuals (Berger, et al, 2008).

Field testing of HPD can be conducted via three methods: subjective (psychoacoustic), objective (acoustic), and non-acoustic. The subjective method determines the real-ear attenuation at threshold (REAT) by using either a sound booth/chamber or earphones. The hearing threshold level is tracked to determine hearing sensitivity with and without HPDs. A sound is emitted from speakers inside the chamber or via the earphones, and the individual notes the perceived level of hearing the noise like audiometric testing; this is conducted with and without HPDs in place. The environment surrounding the testing area needs to be quiet. Often in the field application of the test, earphones are used instead of the chamber, thus limiting the testing of HPD to only earplugs. The Loudness- Balance method is included in the subjective category since it requires the participant to balance the sound levels between each year (Berger, et al, 2008). The VeriPRO from Howard Leight uses the Loudness-Balance method. The objective method uses microphone-in-real-ear (MIRE), in which a microphone is placed through an earplug or earmuff and measures the sound pressure levels both inside and outside the ear. The background environment does not need to be as quiet as the REAT method. However, the insertion of the probe in the earplugs does place a limit on the applicability of the testing system to the use of everyday earplugs. The non-acoustic method uses static pressure and pneumatic seal measurements to determine fit. This method is generally used to determine the fit of custom earplugs to ensure it seals the ear effectively. It cannot be applied to foam earplugs since they do not form a pneumatic seal about the ear canal (Berger, et al, 2008).

The 3M E-A-RFit Dual Validation System (E-A-Rfit), which has been made available in the last five years, can be used to measure how 3M brand HPD fit select individuals. The E-A-Rfit uses a Field-Microphone-In-Real-Ear (F-MIRE) that measures a white noise emitted by the test speaker in seven different frequencies (125 Hz to 8000 Hz) (3M, 2017). The participant receives a personal attenuation rating (PAR) based on the noise reduction and insertion loss (adjusted mathematically via the transfer function of the open ear (TFOE) which is the difference between the SPLs at the eardrum and in the sound field) for the selected HPD type. 3M claims that the E-A-Rfit can assist in identifying workers at risk for NIHL based on low PAR scores, and those in need of additional training and intervention. Variability of an individual's insertion of the earplug provides some uncertainty in the measurement that is accounted for the software output (Berger, et al, 2008). Trompette, et al, in 2014, studied the intra-variability of 20 subjects using the E-A-Rfit for three rounds of tests and found a two dB difference with a maximum range of four to seven dB between the three tests (Trompette, et al, 2014).

Employees in the military, manufacturing, petrochemical, and research facilities were tested for fit using the F-MIRE method on the E-A-Rfit system for the PAR of two foam earplugs: the 3M™ E-A-R™ Classic™ (Classic) made from polyvinyl chloride and the 3M™ E-A-Rsoft™ Yellow Neons™ (Yellow Neons) made from tapered polyurethane. The results of the distribution of PAR from the Classic plug were unimodal, but skewed towards the right for higher PAR. The range of the PAR was 14-43 dB with a mean of 29 dB. Out of the test employees, 98% achieved an effective real-world NRR (computed using a two dB C-A correction factor to compare the NRR to the PAR) of 18 dB. This means that 98% of the employees should have obtained a PAR of 27 dB by subtracting the correction factor of two dB from the manufacturer NRR of 29 dB; however, only 73% of employees were able to obtain this measurement. The results of the distribution of PAR for the Yellow Neons were bimodal showing groups of both high and low PAR. The range of the PAR was 6-42 dB with a mean of 26 dB. The Yellow Neons achieved an effective real-world NRR of 10 dB. 98% of employees should have obtained a PAR of 31 dB; however, only 38% were able to achieve that anticipated PAR (Berger, et al, 2008). This study highlights the variability between individuals on PAR when inserted normally for daily use. A study by Neitzel in 2005 found high variability in PAR for the three different HPD groups that were tested on construction workers using the FitChek system. Neitzel also found that the construction workers could achieve >50% of the adjusted NRR, with a mean PAR of 19.5 dB (Neitzel and Seixas, 2007). Another study by Voix and Hager published in 2015 concluded that the F-MIRE method is a useful and simple tool for hearing conservation efforts that allows for individual fit testing in an objective manner (Voix and Hager, 2015).

Objectives

Providing individuals with a PAR helps them to understand which HPD type provides them with the best protection against noise sources, and that the manufacturer's denoted NRR might not hold true for them individually. Comfort and fit vary between individuals, and the different types of HPD might provide different levels of protection for different people. The E-A-Rfit also can assist in showing the participants how the HPD should feel in the ear when providing higher levels of protection. The E-A-Rfit is a portable, educational tool that can be used to train people on how to properly insert hearing protection while providing them with personal fit information in industrial training settings and during farm outreach events in the hopes of decreasing the prevalence of hearing loss.

The aims of this study were to:

1. Compare the PAR to the manufacturer's NRR and the adjusted NRR-7
2. Compare PAR attained within each study population (agricultural vs industrial workers)

The 3M™ E-A-R™ Classic™ (Classic), 3M™ E-A-Rsoft™ Yellow Neons™ (Yellow Neons), 3M™ E-A-R™ Ultrafit™ (Ultrafit), 3M™ E-A-R™ Push-Ins™ (Push-Ins) were tested in this study.

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Chapter 2

Introduction

Hearing loss is currently the third most common physical and chronic condition in the United States (Carroll, 2017). Recent estimations report one in four adults have high frequency hearing loss (Carroll, 2017). An estimated 30 million people are at risk for noise-induced hearing loss from occupational and recreational activities (Rogers, et al, 2009). Workers in the manufacturing and agricultural industries are at a higher risk for exposure to noise compared to other sectors (Rogers, et al, 2009).

A timeline of hearing protection history in the United States shows slow progress for the development of new noise standards with little to no reduction in the prevalence of hearing loss among workers. The Occupational Safety and Health Administration (OSHA) Noise Standard (29 CFR 1910.95) was promulgated in 1971 for general industry workers (agricultural workers are not covered under the standard), which outlined exposure limits, sampling requirements, and set the permissible exposure limit (PEL) for an eight-hour time weighted average (TWA) is 90 decibels-A-weighting (dBA) with a five dB exchange rate. The Hearing Conservation Amendment was added 10 years later to provide further regulations to prevent hearing loss among workers exposed to noise sources above 85 dBA by requiring workers to be enrolled in a hearing conservation program, to receive annual training on hearing protection, receive annual audiograms, and for employers to provide employees with hearing protection devices (HPD) (United States, Occupational Safety and Health Administration). During the 1980's, the Center for Disease Control (CDC) reported that 17% of production workers have occupational related hearing loss, with 5% having moderate to severe hearing loss. The National Institute of Occupational Safety and Health (NIOSH) also estimated in the 1980's, approximately 25% of people ages 55 and older exposed to noise levels over 90 dBA have hearing loss (MMWR, 1986). NIOSH's Criteria for a Recommended Standard: Occupational Exposure to Noise, published in 1972, was updated in 1998 with recommendations for an exposure limit of 85 dBA, 3 dB exchange rate for an eight hour TWA after research found that the excess 40 year lifetime exposure risk for developing hearing loss from noise levels exceeding 85 dBA would only be 8% as compared to a 25% excess exposure risk of developing hearing loss from noise levels exceeding 90 dBA (NIOSH, 1998). This recommendation followed the American Conference of Governmental Industrial Hygienists (ACGIH) recommendation for an eight hour TWA of 85 dBA, 3 dbA exchange rate in 1994 (ACGIH, 2014). In 2013, the findings from the Occupational Hearing Loss Surveillance Project initiated by NIOSH in 2009 indicated that 18% of workers have hearing loss (CDC Stacks, 2013). Currently, one in three adults reporting exposure to noise sources at work had an audiogram indicating evidence of hearing loss (Carroll, 2017).

There are differences in the prevalence of noise induced hearing loss (NIHL) between: the industrial and agricultural industries, male and female workers, and age groups. For both the industrial and agricultural industries, NIHL is more prevalent among male workers than female workers, with increasing hearing loss as workers age (Carroll, 2017; Masterson, et al, 2013, Beckett, et al, 2000). An estimated 18% of workers ages 18-65 were found to having hearing loss based on audiograms supplied to NIOSH from 2000-2008. Male industrial workers were 2.5 more likely to have hearing loss compared to female workers, and workers aged 56-65 years old were 19 more likely to have hearing loss than workers 18-25 years old (Masterson, et al, 2013). The reported prevalence of hearing loss among agricultural workers varies among studies: 35% of Rabinowitz's study participants self-reporting hearing loss and 50% have documented hearing loss from audiometric testing (Rabinowitz, 2005); 72% of Beckett's study participants have documented hearing loss in the 3000-6000 Hz frequencies (Beckett, et al, 2000). Within the farming population, 25% of male farmers have hearing loss by the age of 30, and 50% have hearing loss by the age of 50 (Ehlers, 2011). Farmers are more likely to have hearing loss compared to non-farmers (McCullagh, et al, 2016).

Three primary methods can reduce the risk of developing hearing loss from occupational exposures: reduce noise levels in the work environment, limit the duration of noise exposures, and effective use of HPD. The reduction or elimination of noise is not always feasible at the workplace, and rotating job duties may be insufficient to reduce exposures over a full shift. Many workplaces rely on using HPD to reduce the noise transmitted from the workplace to the ear. The manufacturers of HPD are required to provide information on how effective these devices are at reducing noise transmitted to the ear, and most single-use packaging of HPD displays the manufacturer's noise reduction rating (NRR). To use this NRR in the workplace, the NRR must be adjusted to the A-weighting scale to by subtracting seven dB from the NRR in order to compare the NRR to workplace noise measurements.

Reliance on HPD by workplaces to reduce noise exposure levels has not led to reductions in the prevalence of hearing loss among workers. Despite having HPD available at worksites or requiring workers to wear HPD, the use of HPD is not consistent. A study examining self-reporting questionnaires in Canada and the National Health and Nutritional Examination Survey in the United States found that only 34% of

United States workers reported using HPD when required compared to 60% of Canadian workers, and only 5% of workers in a Malaysian study provided with HPD wore them regularly (Feder, 2017, Maisarah and Said, 1993). Comfort and personal perceptions of risk are two reasons why workers do not consistently wear HPD (Arezes and Miguel, 2002). Despite the inconsistent use of HPD by workers, studies claim that HPD can prevent hearing loss when used consistently (Rabinowitz, 2000; McCullagh, et al, 2016). The actual attenuations of HPD used by workers in their work environments and the factors that influence the fit of HPD (anatomy, size, material, etc.) have not been thoroughly examined until recently with the use of fit testing devices. The personal attenuation ratings (PAR) for HPD achieved by workers often do not match the NRR, though training in conjunction with fit testing improve the noise attenuation achieved by workers (Liu, 2016). Hearing protection devices need to be properly fitted in the ear [and be consistently worn] to reduce noise exposure to a level that protects against the development of hearing loss (Carroll, 2017).

Despite the national hearing conservation efforts progressing since the 1970's, there has been little progress in decreasing the prevalence of NIHL. The reliance of HPD as a method of reducing noise exposure leads to the hypotheses that either workers are not using HPD as expected, or that the selection and fit of HPD is insufficient. This study focused on the selection and fit of HPD among industrial and agricultural workers by measuring the PAR of four commonly available HPD and comparing the PAR distributions between study populations and between HPD types to the manufacturer NRR to investigate if the types of HPD marketed as universally fitting adequately reduce noise exposure levels.

Methods

Participants

Approval was received from the Institutional Review Board (IRB No. 201604761) prior to enrolling participants. The two study groups consisted of convenience samples of both agricultural and industrial workers in the Midwest. The agricultural participants were recruited at two farm shows and two county fairs. Agricultural participants were eligible if they lived or worked on a farm and were at least 16 years of age. The industrial workers were recruited from three manufacturing facilities that had active hearing conservation programs; the workers volunteered to participate if they wanted to receive additional training on hearing protection and to learn the effectiveness of the HPD they were wearing.

For all participants, demographic information (age, gender, ethnicity), years working on a farm or in manufacturing, and hearing protection device preference were collected at the start of each participant's test. Enrollment targets of 50 agricultural workers from the farm shows/county fairs and 50 industrial workers were exceeded.

Equipment

The 3M E-A-Rfit™ Dual Ear Validation System (E-A-Rfit) was used to generate each participant's Personal Attenuation Rating (PAR) for up to four HPD models. The microphones were calibrated via the software at the start of testing at each test site and again if the software was restarted during the day. A daily performance check was performed by the operator prior to testing, using the Yellow Neon HPD, to ensure consistent PAR was measured throughout the study.

The fit of four 3M™ HPD were tested: E-A-R™ Ultrafit™ (Ultrafit), E-A-R™ Push-Ins™ (Push-Ins), E-A-R™ Classic™ (Classic), E-A-RSoft™ FX™ (Yellow Neon). The Ultrafit and Push-Ins were selected because of their convenience of insertion, reusability, and availability in regional stores. Two formable plugs with higher NRRs were selected: the Classic, which is widely available, and the Yellow Neon, which is made from a softer material and similar to options found in local farm supply and hardware stores.

Procedure and Experimental Design

After collection of demographic information, participants identified their preferred HPD, which was the first HPD to be tested. Figure 1 displays the experimental setup.

Each participant was asked to insert the probed HPD into their ears. If the participant requested a demonstration on how to insert the formable HPD, then the participant was shown how to roll down HPD, pull back the ear to straighten out the ear canal, insert the HPD, and wait for expansion, as appropriate. If no demonstration was requested, then the participant would insert the first HPD without coaching. Testing followed the E-A-Rfit protocol. The fit performance was assessed using the recorded "PAR dB Binaural MINUS Variability (5 dB) Binaural", referenced as PAR hereafter. If the PAR for the first test was low (<NRR/2) or received a "FAIL" by the software, the participant was coached on insertion and asked if they wanted to repeat the test. The process would then be repeated for each of the three remaining HPD models, with participant selecting the order of the remaining HPD tested. Participation was voluntary and the participants could opt out of the study at any time.

The participant received their fit results for each HPD tested, with an indication of both their PAR and the manufacturer's noise reduction rating (NRR). These results were interpreted for each participant to assist with future HPD selection and use.

Data Analysis

Descriptive statistics were generated to examine demographic information between the two study groups. The PAR measurements were tested for normality for each HPD model tested in two groupings: for first HPD tested and then for each HPD tested regardless of test order ("all tests"). Since the data were neither normal nor log-normal, non-parametric tests (Kruskal-Wallis) were used to compare PAR between genders, employment category and HPD type for the first tests and then all tests. The effect of whether PAR differed within an HPD category was assessed between age quartiles. Age quartiles were calculated for each study group separately, and then for the combination of both study groups. If there was a significant difference ($p \leq 0.05$) in PAR between employment category or age quartiles, odds ratios were computed to assess the proportion of participants achieving PARs equivalent to the A-weighted NRR from the manufacturer (NRR-7). The agricultural workers (employment category) and the youngest age quartile (age quartiles) were used as the referent groups (logistic regression). All tests were performed using SAS Version 9.2, SAS Institute Inc., Cary, NC, USA.

Results

Demographics

There were 136 participants in the study: 60 agricultural workers and 76 industrial workers. A higher proportion of females participated in the manufacturing group (62%) compared to the farming group (23%) (Table 1). The mean age of the participant was 46, with a slightly younger mean age for the agricultural workers (44 years) compared to the manufacturing workers (48 years), although the range of participant ages in agriculture was wider (16-80 years compared to 19-71 years for industry). A total of 536 PAR tests were obtained: 61 of the participants did not test all four HPD and 25% of the total tests were retests. The average PAR for the daily performance check by the operator was 18.2 dBA (SD=8.4 dBA).

First Test

The Yellow Neon (35%) and Ultrafit (33%) were equally popular for the first choice HPD selected by the agricultural group. The Ultrafit (41%) had the highest popularity for the first choice HPD selected by the industrial group. Only nine participants spanning both groups selected the Classic as their first choice, thus limiting analysis of the effectiveness of this HPD as a first choice.

The frequency distribution of PAR for first-tested HPDs are shown in Figure 2. The Ultrafit had the highest percentage of participants achieve the A-weighted adjusted NRR (25%), while the Yellow Neon had the lowest percentage of participants achieving the adjusted NRR (9%). There was no significant difference identified between the agricultural or industrial worker’s ability to achieve PARs at or above the manufacturer’s A-weighted NRR (OR=0.548, CI=0.22-1.355) on the preferred HPD.

All Tests

The frequency distribution of PAR over all HPD tests is illustrated in Figure 3. The non-formable HPD obtained higher percentages of PAR greater than or equal to the A-weighted adjusted NRR compared to the formable HPD despite the fact the formable HPD are marketed to provide better protection with higher NRR ratings (31 and 33 dB). The Push-Ins has the highest percentage (23%) of tests obtaining a PAR greater than or equal to the A-weighted adjusted NRR. The Classic had only 2% of the tests obtaining a PAR greater than or equal to the adjusted NRR.

Table 2 identifies the mean PAR by gender, HPD, and occupational group. Non-parametric (Kruskal-Wallis) tests found that females in the agricultural group obtained a higher average PAR for the Classic HPD compared to males (p=0.04). Within the combination of both study populations, the Ultrafit had a significantly lower average PAR for females (p=0.009). The Ultrafit also had a significantly lower average PAR for males compared to the Push-Ins (p=0.002) for the combination of both study populations.

Age Quartiles

To examine whether differences in HPD fit varied by age, participants in the agricultural group were classified into four age quartiles (16-23, 24-48, 49-61, and 62-80 years old). Table 3 shows the range of PARs (mean PAR per age group) between two age groups if a significant difference was found between them. There were no differences in PAR between HPD types within each age group. However, there were significant differences in PAR between the youngest and oldest group for the Yellow Neon for both the first HPD tested and over all HPD tests (p<0.007). Over all HPD tests, the oldest group had significantly lower PAR for all HPD types, and the youngest age group had a significantly lower PAR for the Ultrafit compared to the Yellow Neon (p=0.02).

The quartiles for the industrial worker ages were 19-37, 38-51, 52-55, and 56-71 years old. Significant differences between age groups by HPD types are also in Table 3. The Push-Ins were the only HPD type that had a significant difference in PAR between age groups for either the first HPD tested or over all HPD tests, with the youngest group obtaining the highest PAR (p<0.05). Within in each age group, the youngest group had a significantly lower PAR for the Ultrafit compared to the Classic, over all tests (p=0.024).

Using quartile age groupings aggregated across both employment groups, (16-20, 21-50, 51-64, 65-80 years old), there were no significant differences in PAR across all

HPD between agricultural workers and industrial workers for any age group (Table 4). The oldest age group had a significantly lower PAR compared to the youngest age group for the agricultural group (p=0.04). However, the odds of achieving a PAR that met or exceeded the A-weighted NRR in the 51-64 year old group was 22% (CI=6.4 – 77.7%) of the rate in the 16-20 year old group. No additional odds ratios were significant.

Discussion

Demographics

The agricultural workers in the study group were 11 years younger (44 years old) than the average age of Midwest farmers (55 years). The average age of the industrial workers was four years older than the average age of the agricultural workers who participated. More male agricultural workers participated than females (46 compared to 14), while more female industrial workers participated than males (47 compared to 29). Despite the studies that report that men and women wear HPD at similar rates in both agriculture (McCullagh, et al, 2016) and blue collar work (Lusk, et al, 2008), men are more likely to have hearing loss than women (Carroll, 2017; Masterson, et al, 2013, Beckett, et al, 2000). This study found that women obtained a significantly higher PAR on average for only the Classic HPD compared to men. Therefore, the difference in hearing loss rates between men and women may not be attributable to the fit of HPD, but rather significantly louder noise exposures for men than women.

First and All Tests

Neitzel and Seixas (2007) evaluated the HPD attenuation using the FitCheck system for 44 construction workers. Tests that included the same Classic HPD found a mean binaural personal attenuation of 19.5 dB (SD =9.1), which was higher than found in this study. Cassano et al. (2013) performed a limited study of eight young subjects, trained to insert the earplug, and reported PARs from the E-A-Rfit device were 10 dB lower than the manufacturer's single number rating for the HPD (unspecified model). The results of the Cassano, et al. study are comparable to this study, since approximately 75% of the tests resulted in a PAR that was less than the A-weighted adjusted NRR. Murphy et al. (2015) found in two different field studies of oil rig inspectors using the NIOSH HPD Well Fit^{TM} that 39-44% of the workers could not obtain a PAR of 25 dB on the first fit test, but after multiple tests and HPD selections, 85-89% eventually obtained a PAR of 25 dB. The results of the oil rig workers differ from the results in this study, as only 6% of both the agricultural and industrial workers obtained a PAR of 25 dBA or greater for both the first test and over all tests. Berger et al. (2008) found a mean PAR of 29 dB (range of 14-43 dB) for the Classic and a mean of 26 dB (range of 6-42 dB) for the Yellow Neons from data collected over seven studies involving 196 participants from military, manufacturing, research, and petrochemical facilities. Only 73% of their participants obtained an NRR of 27 dB (2 dB C-A correction) for the Classic and only 38% obtained an NRR of 31 dB for the Yellow Neons. Bergers results are highly different than the results found in this study. No participants obtained a PAR of at least 27 dBA for the Classic, and only 1 test (<2%) resulted in a PAR of at least 31 dBA for the Yellow Neon.

The reasoning behind including two employment groups in this study was to test the hypothesis that the industrial workers, who have actively participated in hearing conservation programs, would achieve higher PARs compared to agricultural workers, who have little experience in selecting and using HPD. This presumed that training result in higher levels of protection since the employees were in hearing conservation programs and undergo annual training that would enhance their ability to insert the HPD into their ears. Examining baseline performance of the PAR for the first-plug tested, we failed to observe a significant or substantial difference in PAR between the two employment groups, with a statistically insignificant larger mean PAR for the agricultural workers of 1.1 dBA compared to industrial workers. Therefore, other factors beyond the fit of the HPD may be contributing to the increase in hearing loss rates among agricultural workers when compared to industrial workers.

The manufacturer of the four HPD used in the study, 3M, recommends on their website to reduce the NRR by 50% to provide a more accurate representation of the attenuation achieved by workers. Approximately 50% of all tests performed in this study had a PAR that met the recommended adjustment, and approximately 45% of the tests met the recommendation on the first test only. Higher percentages of the agricultural workers met or exceeded the 3M recommendation (56% all tests, 48% first tests) compared to the industrial workers (45% all tests, 42% first tests). Since greater percentages of the tests resulted in PARs that met or exceeded half of the A-weighted adjusted NRR, (NRR-7)/2 compared to those that only met the A-weighted adjusted (NRR-7), 3M should consider increasing the emphasis this information to customers, as it is only written in small text under the product description.

Age Quartiles

As age increases, the prevalence of hearing loss increases, especially among males (Carroll, 2017; Masterson, et al, 2013). Workers between the ages of 56-65 years of age are 19 times more likely to have hearing loss (Masterson, et al, 2013). However, this study identified that for a worker between the ages of 51-64, the odds of obtaining a PAR greater than the A-weighted NRR (NRR-7) was reduced to only 22% of the youngest age group of workers (i.e., 16-20 years of age). Therefore, since ear size continues to increase over a lifetime (Niemitz, et al., 2007), older workers may not be able to obtain a "good fit" as well as the younger workers. Therefore, assessing the fit of HPDs over a working lifetime is essential to ensure that HPDs continue to fit properly and protect workers' hearing as they age.

Limitations

An inter-laboratory study comparing three HPD fit testing systems using the real-ear attenuation at threshold (REAT) methods to the ANSI standard method found that participants did not obtain a better fit in the HPD between the first trial and the second trial; the participants did not receive any demonstrations in between the two trial tests (Byrne, et al., 2016). In this study, there were some improvements between the first test and repeated tests with the same HPD type. However, out of the 536 total tests, only 136 of the tests were repeated, and of the retests, 32% (n= 44) obtained a higher PAR (mean=16 dBA, SD=7.5 dBA) compared to the first HPD selected for testing. This study identified that hands-on coaching immediately following a first test of an HPD may provide additional education necessary to protect hearing.

Inter-subject and intra-subject variability could have influenced the results of this study. Trompette et al. (2014) examined the intra-subject variability of 20 subjects in the E-A-Rfit system using the four HPD included in this study. Three tests were performed on each participant with refitting of the HPD in between tests with a mean difference in PAR of 2 dB between tests. Though participants tested four different HPD in this study, with 136 tests repeated, the intra-subject variability would not have a substantial impact on the results based on the analysis used, except for those few tests that were bordering the adjusted NRR by 1 dB. The anatomical differences, desire to find HPD that fit, and the testing environment (outdoor vs indoors, temperature) between participants also needs to be noted, which may have influenced the fit of the HPD despite the training and other factors examined.

Conclusion

Of the 536 tests conducted on 136 workers who wore up to four HPD, less than 25% achieved personal attenuation ratings at or above the A-weighted NRR. Relying on the manufacturer's NRR, even with A-weighting adjustments, is insufficient to evaluate the effectiveness of HPD to reduce noise exposures in the workplace. Personal attenuation ratings for four standard HPDs were *not* significantly higher for industrial workers compared to agricultural workers, even though they have participated in workplace hearing conservation programs and have received annual training and demonstrations on how to insert HPD. Workers younger than 21 years of age achieved higher PARs compared to older workers for the Push-In HPD in industry and for all HPD in agriculture, indicating that monitoring of the effectiveness of HPD is repeatedly conducted over a work lifetime. Gender differences in PAR were insignificant, except for female agricultural workers obtaining a higher PAR for the Classic HPD compared to the male workers. In order to protect workers from high noise levels, personal attenuation assessments and customized training may be necessary to improve the effectiveness of HPD, which may be the critical step in reducing the burden of hearing loss among workers in the US and abroad.

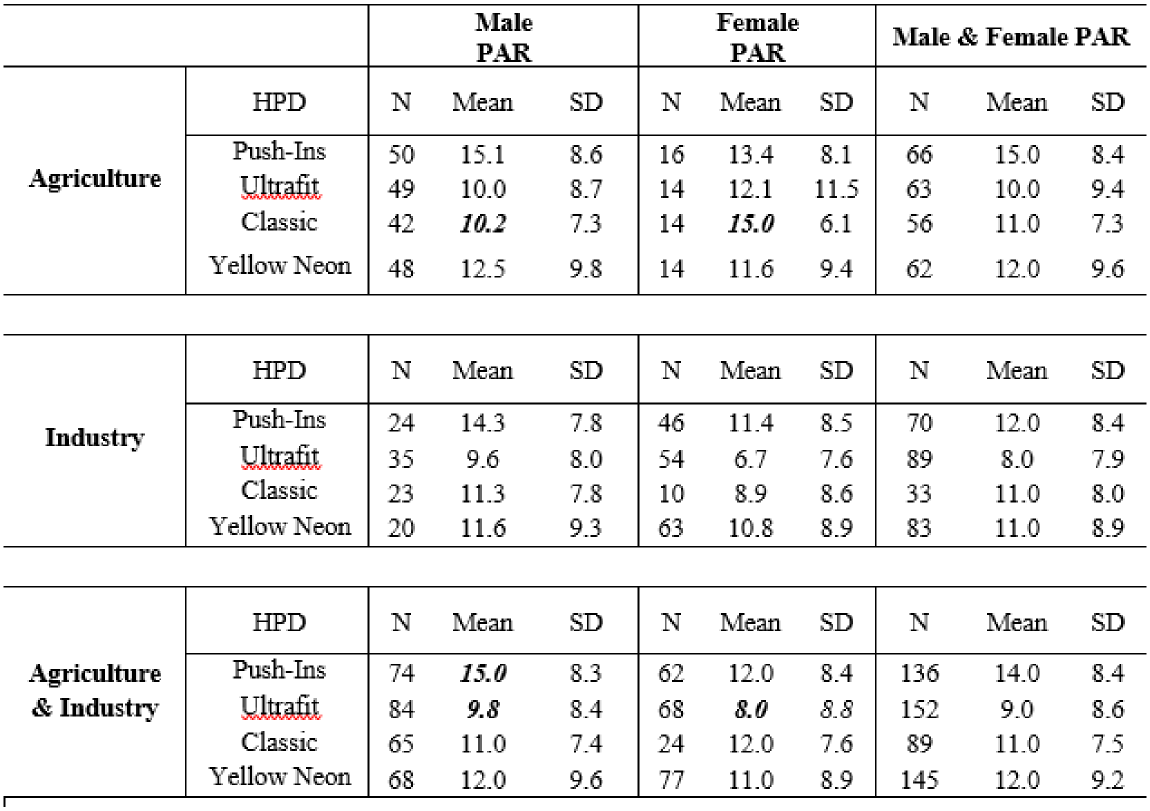
Tables

Table 1. Demographic Information

	Agriculture	**Industry**	**Total**
Total Participant Count	60	76	136
Total Count of Plugs Tested	247	275	536
Count (%) of Participants by Gender:			
Male	46 (77%)	29 (38%)	75 (55%)
Female	14 (23%)	47 (62%)	61 (45%)
Mean (SD) Participant Age	44 (20)	48 (13)	46 (17)
Mean (SD) Male Age	46 (20)	48 (14)	47 (18)
Mean (SD) Female Age	40 (20)	47 (13)	46 (15)
Mean (SD) No. Years Worked:			
Years On Farm	28 (17)	16 (11)**	-
Years Off Farm	34 (16)*	17 (10)	-
Mean (SD) PAR	10.9 (9.4)	9.8 (8.9)	10.2 (9.1)

*Farmers with additional industry experience
**Industrial workers with additional farming experience

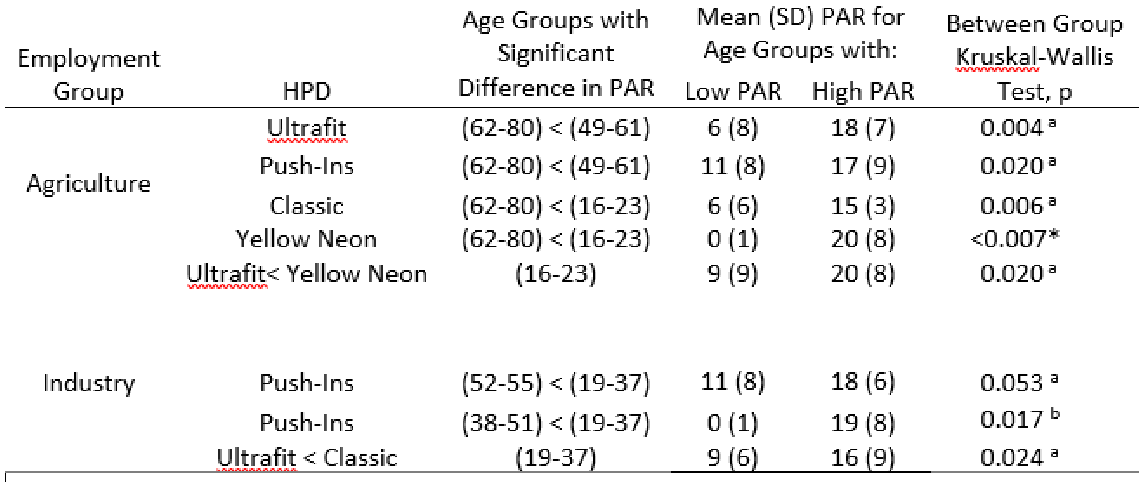
Table 2. PAR by Occupation Groups, HPD Type, and Gender for All Plugs



		Male PAR			**Female PAR**			**Male & Female PAR**		
	HPD	N	Mean	SD	N	Mean	SD	N	Mean	SD
Agriculture	Push-Ins	50	15.1	8.6	16	13.4	8.1	66	15.0	8.4
	Ultrafit	49	10.0	8.7	14	12.1	11.5	63	10.0	9.4
	Classic	42	***10.2***	7.3	14	***15.0***	6.1	56	11.0	7.3
	Yellow Neon	48	12.5	9.8	14	11.6	9.4	62	12.0	9.6
	HPD	N	Mean	SD	N	Mean	SD	N	Mean	SD
Industry	Push-Ins	24	14.3	7.8	46	11.4	8.5	70	12.0	8.4
	Ultrafit	35	9.6	8.0	54	6.7	7.6	89	8.0	7.9
	Classic	23	11.3	7.8	10	8.9	8.6	33	11.0	8.0
	Yellow Neon	20	11.6	9.3	63	10.8	8.9	83	11.0	8.9
	HPD	N	Mean	SD	N	Mean	SD	N	Mean	SD
Agriculture & Industry	Push-Ins	74	***15.0***	8.3	62	12.0	8.4	136	14.0	8.4
	Ultrafit	84	***9.8***	8.4	68	***8.0***	*8.8*	152	9.0	8.6
	Classic	65	11.0	7.4	24	12.0	7.6	89	11.0	7.5
	Yellow Neon	68	12.0	9.6	77	11.0	8.9	145	12.0	9.2

Bold and italicized identifies significantly different PARs, Kruskal-Walis p < 0.04.
(NRR-7): Push-Ins=21; Ultrafit=19; Classic=24; Yellow Neon=26 dBA.

Table 3. Identification of significant PAR, dBA, differences by participant age, over all tests and first tests



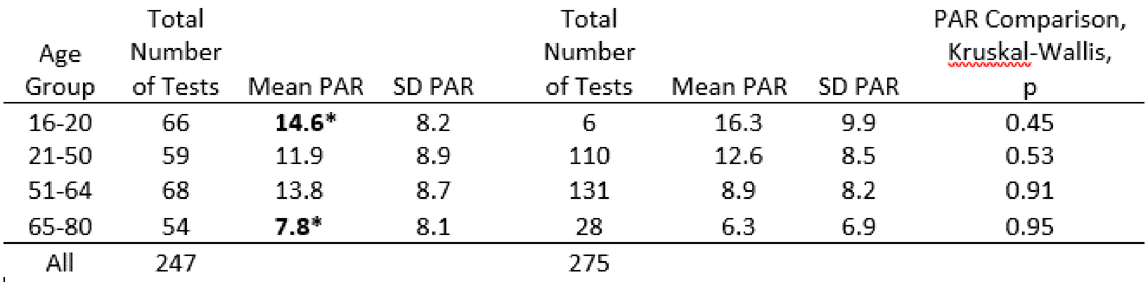
Employment Group	HPD	Age Groups with Significant Difference in PAR	Mean (SD) PAR for Age Groups with: Low PAR	Mean (SD) PAR for Age Groups with: High PAR	Between Group Kruskal-Wallis Test, p
Agriculture	Ultrafit	(62-80) < (49-61)	6 (8)	18 (7)	0.004 [a]
	Push-Ins	(62-80) < (49-61)	11 (8)	17 (9)	0.020 [a]
	Classic	(62-80) < (16-23)	6 (6)	15 (3)	0.006 [a]
	Yellow Neon	(62-80) < (16-23)	0 (1)	20 (8)	<0.007*
	Ultrafit< Yellow Neon	(16-23)	9 (9)	20 (8)	0.020 [a]
Industry	Push-Ins	(52-55) < (19-37)	11 (8)	18 (6)	0.053 [a]
	Push-Ins	(38-51) < (19-37)	0 (1)	19 (8)	0.017 [b]
	Ultrafit < Classic	(19-37)	9 (6)	16 (9)	0.024 [a]

*Significant for both first plug tested and over all plugs tested

[a]Significant over all plugs tested

[b]Significant over first plug tested only

Table 4. Comparison of PAR differences between occupational groups, by age quartile using all HPD tested



Age Group	Total Number of Tests	Mean PAR	SD PAR	Total Number of Tests	Mean PAR	SD PAR	PAR Comparison, Kruskal-Wallis, p
16-20	66	**14.6***	8.2	6	16.3	9.9	0.45
21-50	59	11.9	8.9	110	12.6	8.5	0.53
51-64	68	13.8	8.7	131	8.9	8.2	0.91
65-80	54	**7.8***	8.1	28	6.3	6.9	0.95
All	247			275			

***Values were significantly different, e.g., between age groups 16-20 and 65-80 for agriculture, p<0.04.**

Figures

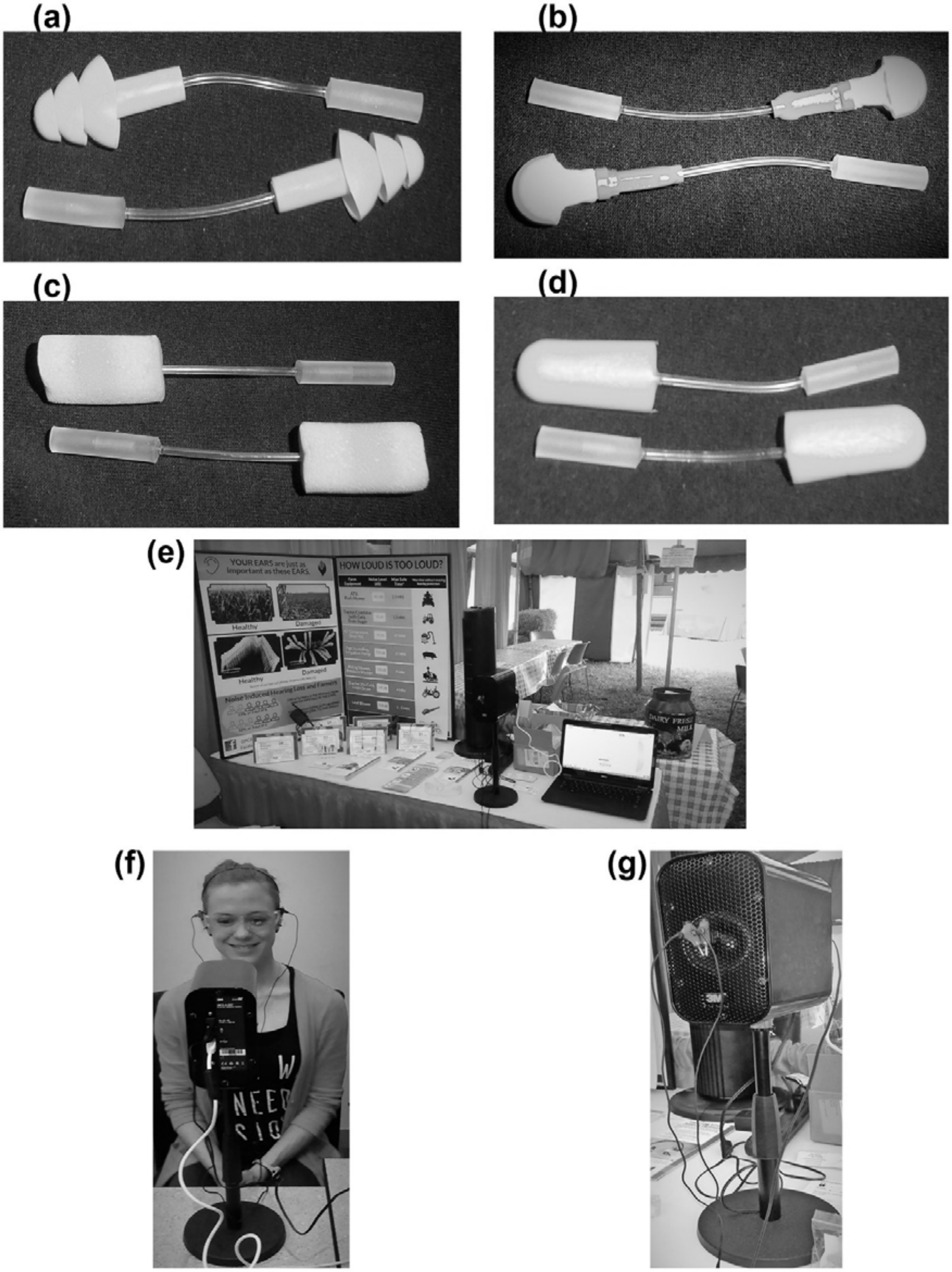


Figure 1. Equipment and Experimental Setup a) Ultrafit b) Push-Ins c) Classic d) Yellow Neons e) Setup of EARFit at farm show f) Participant during testing g) Speaker with microphones

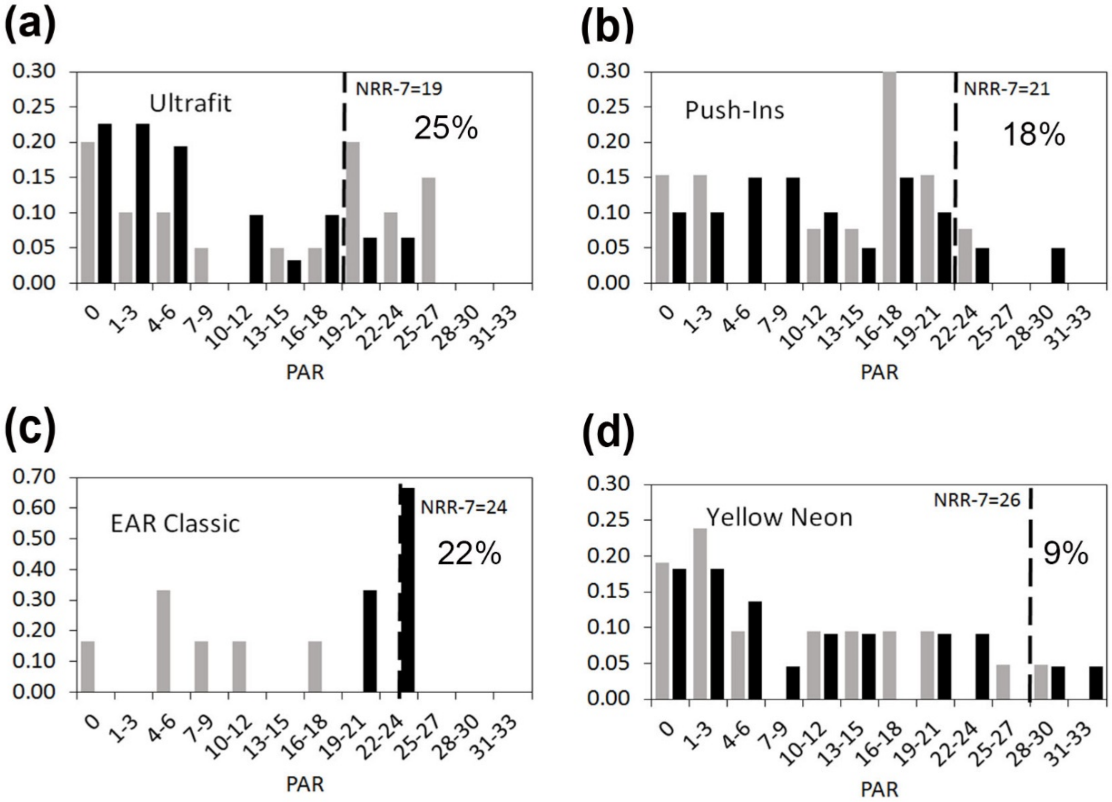


Figure 2. Fraction of participants obtaining PAR result for first HPD tested for (a) Ultrafit, (b) Push-Ins, (c) Classic, and (d) Yellow Neon. Gray bars represent farmers, black bars indicate industry workers. The "NRR-7" provides the manufacturer's A-weighted Noise Reduction for each HPD

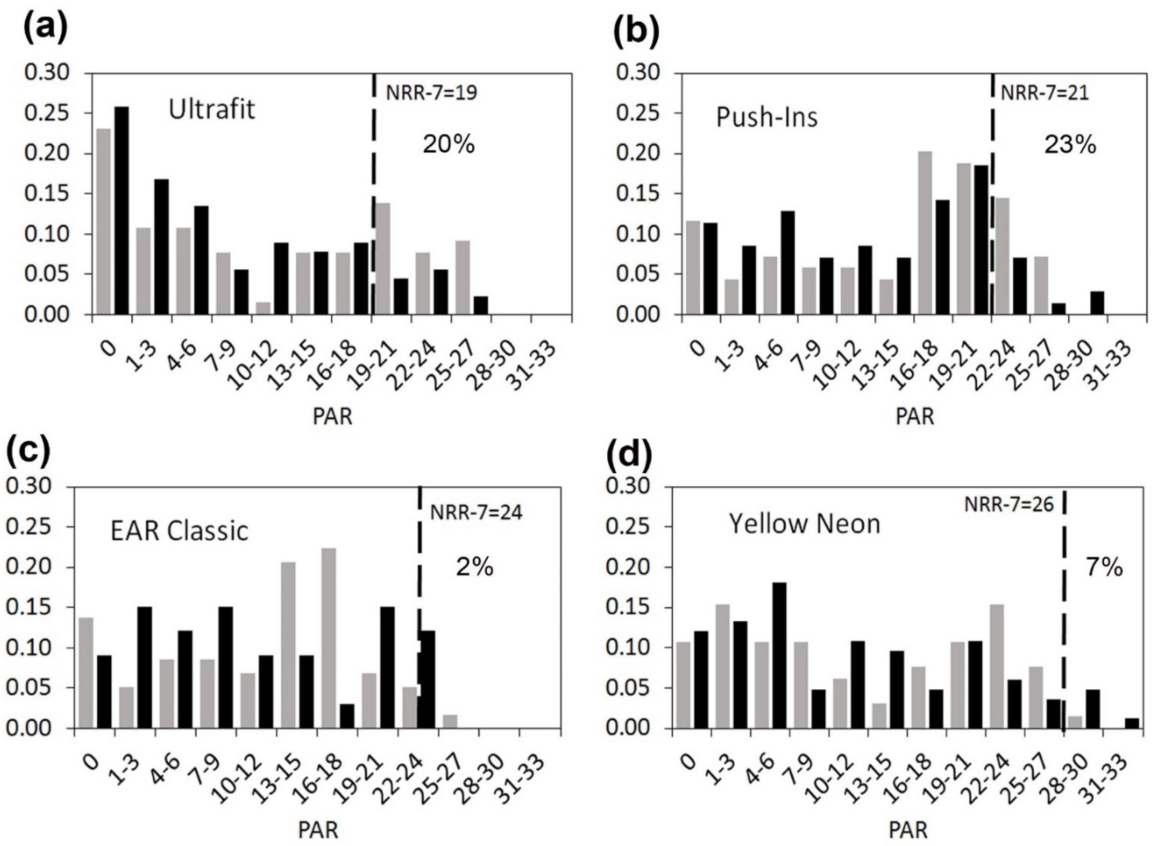


Figure 3. Fraction of participants obtaining PAR result for all HPD tested for (a) Ultrafit, (b) Push-Ins, (c) Classic, and (d) Yellow Neon. Gray bars represent farmers, black bars indicate industry workers. The "NRR-7" provides the manufacturer's A-weighted Noise Reduction for each HPD

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Chapter 3

Conclusions

The purpose of this study was to evaluate the effectiveness of hearing protection devices via the quantification of the personal attenuation ratings (PAR) achieved by agricultural workers, who receive little to no training on hearing protection, and by industrial workers enrolled in a hearing conservation program. The study provided individual fit testing results to participants while also enabling data to be collected to determine the overall effectiveness of hearing protection during average public use compared to the manufacturer's noise reduction rating. Based on the two different study populations, the effectiveness of training given to workers could also be analyzed based on the combined performance of participants at each location.

The data presented in Chapter II suggests that agricultural and industrial workers are not achieving their desired levelled of protection against noise when inserting ear plugs. Among both the agricultural and industrial workers, the non-formable ear plugs provided higher personal attenuation levels despite having a lower noise reduction rating. This suggests that the average person should select non-formable ear plugs over formable ear plugs to achieve greater protection. Unless inserted specifically as instructed, the formable plugs do not seal in the ear and protect against noise damage as much as they are designed to. The inadequacy of the fit could result from user error in not rolling down the plugs as small as possible, pulling back the ear to straighten the ear canal, and holding the plug in the ear until it fully expands. Based on personal interactions many of the participants did not want to take the time to ensure the earplugs were fitting properly inside the ear or did not want to take the time to roll down the formable plugs and hold them as they expand into the ear canal. One person stated that “rolling down the earplugs and holding them in the ear was too much work. [He] would rather just stick them in there. That is good enough.” Also, people have different sized and shaped ear canals which can affect the fit of the ear plug as it forms to the shape of the canal. Follow up sampling will be conducted on different sized hearing protection devices to see if they provide differing results from the data presented in Chapter II.

The data also suggests that training programs in industry on hearing protection are lacking in ensuring workers understand and can properly insert hearing protection. Workers may know why to wear hearing protection but are either unable to wear the devices in a manner that will provide them optimal protection or are not achieving a proper fit when they wear the devices. This study examined workers at three separate manufacturing locations. Two of the locations had similar training programs in which the workers would watch a yearly training video and then discuss quiz questions together. Neither of the sites had a full-time safety professional or industrial hygienist that would remain at the site throughout the shift, but rather an occupational health nurse that would cover both locations. The third location had a more active training program. The safety professional would present a lecture on hearing protection with demonstrations on insertion. The supervisors were expected to enforce hearing protection use on the plant floor. Throughout the year, trivia events were held which incorporated hearing protection. The data suggests that there were no differences in fit between the manufacturing locations for each plug type (p=0.13-0.59). However, it did appear that individuals who received one on one demonstrations during the fit testing could increase their personal attenuation ratings. This increase suggests that tools that analyze the individual fit of hearing protection should be accompanied into training programs and that more attention should be focused on the individual workers to ensure that the workers can: understand how to wear hearing protection, select devices that work for them, and physically insert the devices to provide optimal protection.

In order to enroll participants in the E-A-Rfit testing, two different strategies were used for the manufacturing workers and the farmers. Farmers were randomly selected at the county fair and farm show locations that the Great Plains Center for Agricultural Health had an educational/outreach booth at. Information on hearing protection, roadway safety, and gas monitors was provided at the booths. Farmers that stopped by the booth to learn more about these three safety and health topics were asked to participate, and they were offered a $10 gift card to a local farm/hardware store. At times, when foot traffic around the booth was slow, people were recruited to come learn more about hearing protection and to try the E-A-Rfit. On the manufacturing side, an email was sent out to a group of occupational health nurses asking if there would be any interest for the sites to participate in the study with the requirement that the participating workers needed to be enrolled in a hearing conservation program. The nurses that replied expressing interest were further contacted to explain more about the study, and to determine the number of workers enrolled in the hearing conservation programs who may be interested in participating. After further discussions, dates were confirmed with the sites to perform the E-A-Rfit testing. The occupational health nurses informed their workers of the study, and asked the workers that were interested to sign up to participate with their own 15-minute time slots.

On a personal level, a greater understanding was gained of the problems people face with wearing personal protective equipment. In school, we gain all the background knowledge on the importance of personal protective equipment, specifically in this case, hearing protection, but we do not often relay this information on to those people it affects or actual wear the devices as often or in the environments that the workers do. Travelling to the different county fairs, farm shows, and manufacturing locations provided opportunities to listen to different groups of people with similar concerns and frustrations. Comfort, difficulty of wearing equipment based on environmental conditions, the perception of protection or lack thereof, and an overall lack of understanding on why or how to wear protective devices were common concerns expressed by the participants. Hopefully, this study will encourage both myself and other industry professionals to work more with individual workers to understand their points of view on safety and industrial hygiene, but also to provide them with better training and protection against hazards. Outreach to farming and other underserved populations is important to ensure that information is passed to those who do not always have access to safety equipment or to the knowledge behind equipment usage. Though this study was conducted on a small portion of Midwest farmers and manufacturing workers, the information gained can be used to improve safety and health programs and outreach activities.

Appendix

Appendix A. Summary data from individual farm shows and facilities

Table A1. Four State Farm Show

		Number Plugs	>5 dB		>10 dB		>NRR		>(NRR/2)	
Plug Type	NRR	Tested	count	%	count	%	count	%	count	%
Classic	31	35	26	74%	19	54%	0	0%	11	35%
Yellow Neon	33	36	27	75%	20	56%	0	0%	15	42%
Push-Ins	28	40	36	90%	32	80%	0	0%	28	70%
Ultrafit	26	35	26	74%	22	63%	2	6%	20	57%
Totals		146	115	79%	93	64%	2	1%	74	51%

Table A2. Johnson County Fair

		Number Plugs	>5 dB		>10 dB		>NRR		>(NRR/2)	
Plug Type	NRR	Tested	count	%	count	%	count	%	count	%
Classic	31	7	5	71%	3	43%	0	0%	2	29%
Yellow Neon	33	12	7	58%	5	42%	0	0%	2	17%
Push-Ins	28	12	9	75%	7	58%	0	0%	7	58%
Ultrafit	26	9	5	56%	4	44%	2	22%	2	22%
Totals		40	26	65%	19	48%	2	5%	13	33%

Table A3. Farm Progress Show

		Number Plugs	>5 dB		>10 dB		>NRR		>(NRR/2)	
Plug Type	NRR	Tested	count	%	count	%	count	%	count	%
Classic	31	10	9	90%	8	80%	0	0%	3	30%
Yellow Neon	33	10	8	80%	6	60%	0	0%	6	60%
Push-Ins	28	10	9	90%	8	80%	0	0%	7	70%
Ultrafit	26	13	7	54%	6	46%	0	0%	6	46%
Totals		43	33	77%	28	65%	0	0%	22	51%

Table A4. Washington County Fair

Plug Type	NRR	Number Plugs Tested	>5 dB		>10 dB		>NRR		>(NRR/2)	
			count	%	count	%	count	%	count	%
Classic	31	13	13	100%	11	85%	3	23%	7	54%
Yellow Neon	33	13	12	92%	11	85%	5	38%	10	77%
Push-Ins	28	15	12	80%	12	80%	3	20%	11	73%
Ultrafit	26	15	9	60%	6	40%	3	20%	6	40%
Totals		56	46	82%	40	71%	14	25%	34	61%

Table A5. Facility A

Plug Type	NRR	Number Tested	>5 dB		>10 dB		>NRR		>(NRR/2)	
			count	%	count	%	count	%	count	%
Classic	31	*8*	*4*	*50%*	*3*	*38%*	*0*	*0%*	*1*	*13%*
Yellow Neon	33	35	21	60%	14	40%	0	0%	8	23%
Push-Ins	28	32	23	72%	17	53%	0	0%	13	41%
Ultrafit	26	43	21	49%	16	37%	1	2%	11	26%
Totals		118	69	58%	50	42%	1	1%	33	28%

Table A6. Facility B

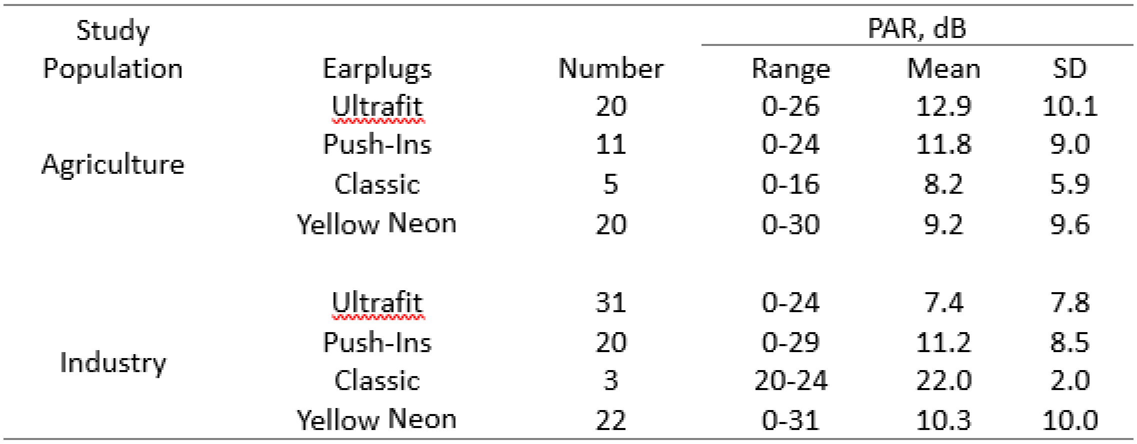
Plug Type	NRR	Number Tested	>5 dB		>10 dB		>NRR		>(NRR/2)	
			count	%	count	%	count	%	count	%
Classic	31	*1*	*1*	*100%*	*1*	*100%*	*0*	*0%*	*1*	*100%*
Yellow Neon	33	25	19	76%	14	56%	0	0%	5	20%
Push-Ins	28	12	10	83%	9	75%	1	8%	7	58%
Ultrafit	26	17	8	47%	6	35%	0	0%	4	24%
Totals		55	38	69%	30	55%	1	2%	17	31%

Table A7. Facility C

Plug Type	NRR	Number Tested	>5 dB		>10 dB		>NRR		>(NRR/2)	
			count	%	count	%	count	%	count	%
Classic	31	24	17	71%	12	50%	0	0%	8	33%
Yellow Neon	33	22	16	73%	14	64%	0	0%	11	50%
Push-Ins	28	26	20	77%	16	62%	1	4%	12	46%
Ultrafit	26	29	17	59%	12	41%	0	0%	8	28%
Totals		101	70	69%	54	53%	1	1%	39	39%

Appendix B. Additional PAR Tables for First HPD Tested

Table B1. Mean, Standard Deviation, and Range of PAR for first HPD tested



Study Population	Earplugs	Number	PAR, dB		
			Range	Mean	SD
Agriculture	Ultrafit	20	0-26	12.9	10.1
	Push-Ins	11	0-24	11.8	9.0
	Classic	5	0-16	8.2	5.9
	Yellow Neon	20	0-30	9.2	9.6
Industry	Ultrafit	31	0-24	7.4	7.8
	Push-Ins	20	0-29	11.2	8.5
	Classic	3	20-24	22.0	2.0
	Yellow Neon	22	0-31	10.3	10.0

Appendix C. Comparison to A-weighted adjusted NRR

Table C1. Percentage of HPD with PAR greater than or equal to the A-weighted adjusted NRR (NRR-7)

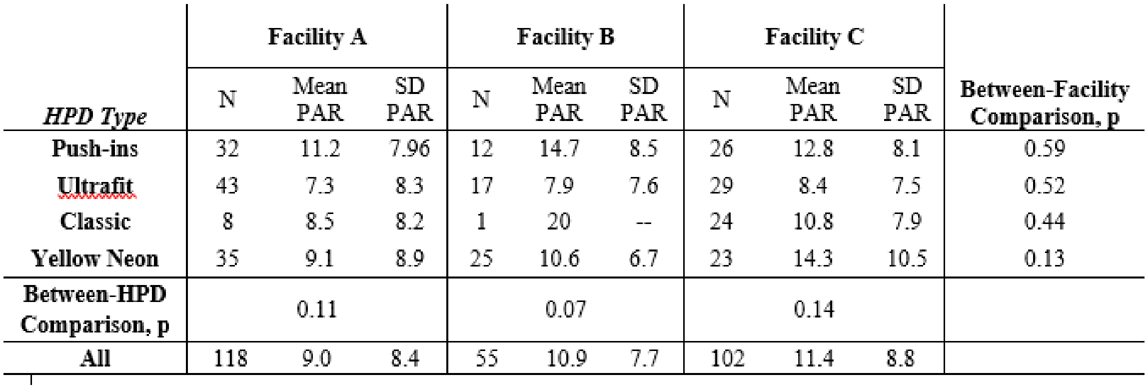
	All Tests				*First Test Only*			
	HPD	NRR-7	Number	%	HPD	NRR-7	Number	%
Agriculture	Ultrafit	19	20/65	31	Ultrafit	19	9/20	45
	Push-Ins	21	19/69	28	Push-Ins	21	2/13	15
	Classic	24	1/58	2	Classic	24	0/6	0
	Yellow Neon	26	4/65	6	Yellow Neon	26	2/21	2
	Total		44/257	18	Total		13/60	22
Industry	Ultrafit	19	11/89	12	Ultrafit	19	4/31	13
	Push-Ins	21	13/70	19	Push-Ins	21	4/20	20
	Classic	24	1/33	3	Classic	24	2/3	67
	Yellow Neon	26	7/83	8	Yellow Neon	26	2/22	10
	Total		32/275	12	Total		12/76	16
Agriculture+Industry	Ultrafit	19	31/154	20	Ultrafit	19	13/51	25
	Push-Ins	21	32/139	23	Push-Ins	21	6/33	18
	Classic	24	2/91	2	Classic	24	2/9	22
	Yellow Neon	26	11/148	7	Yellow Neon	26	4/43	9
	Total		76/532	14	Total		25/136	18

Table C2. Percentage of HPD with PAR greater than or equal to half the A-weighted adjusted NRR, (NRR-7)/2

	All Tests				*First Test Only*			
	HPD	(NRR-7)/2	Number	%	HPD	(NRR-7)/2	Number	%
Agriculture	Ultrafit	10	31/65	48	Ultrafit	10	11/20	55
	Push-Ins	11	49/69	71	Push-Ins	11	9/13	69
	Classic	12	33/58	57	Classic	12	1/6	17
	Yellow Neon	13	30/65	46	Yellow Neon	13	8/21	38
	Total		143/257	56	Total		29/60	48
Industry	Ultrafit	10	34/89	38	Ultrafit	10	11/31	35
	Push-Ins	11	41/70	59	Push-Ins	11	10/20	50
	Classic	12	15/33	45	Classic	12	3/3	100
	Yellow Neon	13	34/83	41	Yellow Neon	13	8/22	36
	Total		124/275	45	Total		32/76	42
Agriculture+ Industry	Ultrafit	10	65/154	42	Ultrafit	10	22/51	43
	Push-Ins	11	90/139	65	Push-Ins	11	19/33	58
	Classic	12	48/91	53	Classic	12	4/9	44
	Yellow Neon	13	64/148	43	Yellow Neon	13	16/43	37
	Total		267/532	50	Total		61/136	45

Appendix D. Facility Comparisons

Table D1. Between-facility comparison of PAR results for all plugs tested for industrial workers, using Kruskal-Wallis test (p). No significant differences were found.



	Facility A			**Facility B**			**Facility C**			
HPD Type	N	Mean PAR	SD PAR	N	Mean PAR	SD PAR	N	Mean PAR	SD PAR	**Between-Facility Comparison, p**
Push-ins	32	11.2	7.96	12	14.7	8.5	26	12.8	8.1	0.59
Ultrafit	43	7.3	8.3	17	7.9	7.6	29	8.4	7.5	0.52
Classic	8	8.5	8.2	1	20	--	24	10.8	7.9	0.44
Yellow Neon	35	9.1	8.9	25	10.6	6.7	23	14.3	10.5	0.13
Between-HPD Comparison, p		0.11			0.07			0.14		
All	118	9.0	8.4	55	10.9	7.7	102	11.4	8.8	

Since three manufacturing locations were included in the manufacturing group, differences in PARs between facilities were examined, with significantly different training programs (two used video and quiz with biannual trivia game reinforcement and the third used PowerPoint training coupled with use demonstrations). However, there were no significant differences in PAR between the facilities, indicating that annual training did not appear to influence personal attenuation for HPD.

Appendix E. Sample SAS codes used throughout data analysis by changing the variables and by groups

Normality:

```
proc univariate data=Noise2 plots normal; title 'Noise Data - Univariate';
var PAR GTFive GTTEN;
by LocationType;
run;
```

Log-normality:

```
data Noise3;
set noise2; lnpar = log(par); run;
proc univariate data=hpdsort plots normal; title 'Noise Data - Univariate';
var PAR ;
by LocationType HPDCode;
run;
```

Nonparametric:

```
Proc NPAR1WAY DATA=age WILCOXON;
Title ‘Nonparametric test to compare PAR between age;
Class locationtype;
VAR par;
by agegroup;
Run;
```

Odds Ratio:

```
proc freq data=Work.dataset;
tables goodNRR*AgeGroup;
run;

proc logistic data=Work.dataset DESCENDING;
class AgeGroup (param = ref ref = "G1");
model  goodNRR = AgeGroup;
oddsratio AgeGroup;
run;
```