THESIS

OCCUPATIONAL EXSPOSURES TO NOISE RESULTING FROM THE WORKPLACE USE OF PERSONAL MEDIA PLAYERS

Submitted by

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ABSTRACT OF THESIS

OCCUPATIONAL EXSPOSURES TO NOISE RESULTING FROM THE WORKPLACE USE OF PERSONAL MEDIA PLAYERS

This study examined the contribution of personal media player (PMP) use in the workplace to overall employee noise exposures at a Colorado manufacturing facility. A total of 24 workers, 12 high-background-noise exposed (HBNE) and 12 low-background-noise exposed (LBNE), were identified as having workplace PMP exposures. A questionnaire was administered to workers who use PMPs to assess occupational PMP use behaviors. In addition, the chosen listening level of each worker was measured using an ear simulator, and the background noise of each workstation was measured using a sound level meter. Chosen listening levels, background noise levels, and self-reported duration of use were used to estimate daily occupational noise exposures.

The measured average background equivalent sound pressure levels were 81 and 59 dBA in high- and low-background noise exposure areas, respectively. The measured average free-field equivalent listening levels from PMPs were significantly greater for HBNE workers (85 dBA) as compared to LBNE workers (75 dBA) ($p=0.0006$). The average self-reported workplace PMP listening time was 3.6 hours per day. The estimated mean daily noise exposures were calculated from background noise and PMP use for both groups and were found to be below the American Conference of

Governmental Industrial Hygienists (ACGIH) standard, specifically 84 dBA eight-hour time weighted average (TWA) for HBNE workers and 72 dBA for LBNE workers. However, 6 of 12 (50%) HBNE workers had estimated daily eight-hour TWA exposures greater than 85 dBA, while none of the LBNE workers exceeded ACGIH standards. The average difference between free-field equivalent listening levels and background noise levels (signal-to-noise ratio) was significantly higher in the LBNE workers (16 dBA) than HBNE workers (4 dBA) due to the selection of sound isolating headsets by HBNE workers.

It is recommended that industries either limit workplace PMP use among HBNE workers or require output limiting technology to prevent occupational noise-induced hearing loss. Further research is needed to estimate the prevalence of occupational PMP use and to determine a background noise level threshold where allowing PMPs at work poses a significant hazard to worker health and safety.

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DEDICATION

For my wife, Amber, and our sons, Anthony and Jacob

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LIST OF ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
ANSI	American National Standards Institute
CSU	Colorado State University
DRC	Damage-Risk Criteria
FFL_{Aeq}	Free-Field Equivalent A-Weighted Sound Pressure Level
HATS	Head and Torso Simulator
HCP	Hearing Conservation Program
HBNE	High Background-Noise-Exposed
IRB	Institutional Review Board
ISO	International Organization for Standardization
L_{Aeq}	Equivalent A-Weighted Sound Pressure Level
L_{eq}	Equivalent Sound Pressure Level
LBNE	Low Background-Noise-Exposed
NIDCD	National Institute on Deafness and Other Communication Disorders
NIHL	Noise-Induced Hearing Loss
NIOSH	National Institute of Occupational Safety and Health
ONIHL	Occupational Noise-Induced Hearing Loss
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PMP	Personal Media Player
PPE	Personal Protective Equipment
PTS	Permanent Threshold Shift
SLM	Sound Level Meter

SPL	Sound Pressure Level
TWA	Time Weighted Average
TTS	Temporary Threshold Shift

CHAPTER 1: INTRODUCTION

Noise is commonly defined as any unwanted or undesirable sound. The normal human ear and nervous system have the remarkable capacity to receive and perceive sound (and noise). However, numerous diseases can impair or completely nullify normal hearing capabilities. Sensorineural hearing loss is one such disease in which hair cells of the inner ear (stereocilia) lose the ability to transmit sound information to the brain. Noise-induced hearing loss, which is damage to stereocilia caused by exposures to hazardous levels of noise, is the second most common etiology of sensorineural hearing loss (Rabinowitz, 2000). Although there are many sources of hazardous noise and types of hearing impairment, workplace noise exposures are the best predictor of hearing impairment other than age in the United States (U.S.) (Wallhagen, Strawbridge, Cohen, & Kaplan, 1997). Sensorineural noise-induced hearing loss caused by exposure to hazardous levels of workplace noise has been termed occupational noise-induced hearing loss (ONIHL).

ONIHL is 100 percent preventable, but remains a substantial contributor to the overall hearing impairment of the U.S. working population. It has been well established that hazardous levels of workplace noise can cause ONIHL. According to the National Institute on Deafness and Other Communication Disorders (NIDCD), an estimated twenty-six million Americans may suffer from noise-induced hearing loss (NIHL) (NIDCD, 2008). The National Institute for Occupational Safety and Health (NIOSH) has estimated that as many as 30 million American workers are exposed to hazardous levels of noise that could contribute to ONIHL, specifically levels greater than 85 dBA as an eight-hour time weighted average (TWA) (NIOSH, 2001). Given this unacceptable number of overexposed workers, NIOSH has identified hearing loss as one of the 21 priority areas for research and maintains that ONIHL continues to be a critical workplace safety and health issue. ONIHL is one of the most common occupational diseases and the second most self-reported occupational illness or injury (Bureau of Labor Statistics [BLS], 2006). Machinery, equipment, and work practices are typically the sources of excessive noise in the workplace. However, workers may unknowingly contribute to their noise exposures in the workplace by using personal media players (PMPs), such as the Apple iPod and other MP3 players, cellular phones with media listening options, and computer based media programs listened to with headsets, especially if used to mask other occupational noise sources.

The popularity of portable radios and media players since the introduction of the Sony Walkman radio in 1980 has grown substantially, and increased again in recent years with the introduction of the iPod in 2001. As the technology of these listening devices has advanced, such as increased media storage and prolonged battery life, so has the ability to enjoy media more conveniently and for longer periods of time, both recreationally and at work. Further, devices with internet connectivity provide virtually infinite media listening libraries. In a 1987 Occupational Safety and Health Administration (OSHA) Standard Interpretation Letter, Dr. John Barry wrote, "… listening to a Walkman unit at more than 50% to 75% rated output will generate sound levels in excess of the OSHA PEL [permissible exposure limit] creating a threat to the wearer's hearing, and this may also produce a safety hazard by masking environmental sounds that need to be heard." (OSHA, 1987). Although the technology cited in the 1987 letter is now obsolete, the general concept and concern are still the same. Based upon recent PMP use studies in non-work environments, PMP use alone has been shown to cause overexposures to noise. Anecdotal evidence suggests that many workers across a variety of occupational sectors use PMPs on the job, though the impact of this use is unclear. The primary focus of this study was to determine if workers are exposing themselves to hazardous levels of occupational noise by using PMPs in the workplace.

CHAPTER 2: LITERATURE REVIEW

Sound and Noise:

Sound is the variation of pressure in an elastic medium (such as air) caused by a mechanical disturbance. The movement of molecules in a transmitting medium caused by a disturbance results in pressure oscillations above (compressions) and below (rarefactions) the ambient pressure level. The oscillation of sound pressure variations is referred to as a sound wave. A sound wave will move through an ideal medium longitudinally and omnidirectionally. The oscillation frequency of a sound wave determines the pitch of a sound, which is measured in Hertz (Hz). The healthy human ear can typically discern frequencies between 20 and 20,000 Hz. The amplitude of the pressure oscillations of a sound wave describes the amount of energy in the wave. The healthy human ear can detect sound wave amplitudes ranging from as low as 20 Micropascals (µPa) to well over 200 Pascals (Pa) of pressure relative to ambient levels. Because of the wide range of amplitude sound pressures, a logarithmic decibel (dB) scale is used to describe sound pressure level (SPL) measurements. SPL is calculated by taking 20 times the base-ten logarithm of the ratio of measured sound pressure over a reference sound pressure (20 µPa), which is commonly considered to be the threshold of human hearing. The resulting SPL dB scale is less cumbersome to work with, as the range of 20 µPa to 200 Pa (seven orders of magnitude) simplifies to a range of 0 dB to 140 dB.

When sound waves travelling in air come into contact with an object they are reflected, attenuated, or transmitted through the material. Hard surfaces such as smooth wood or metal often reflect sound waves well but attenuate sound poorly. Conversely, soft, porous surfaces usually reflect sound waves poorly but attenuate sound waves well. Reflected sound waves can increase the overall SPL in an area, as the reflected wave essentially becomes an additional sound source. Sound behaves predictably in the far-field (i.e., far enough away from individual sound sources relative to the size of the sound sources) and most sound measurement equipment can only accurately measure SPLs in the far field. The measurement of sound generated by a source within a reflective chamber (reverberant-field) is more difficult because the large number of reflections increase the overall SPL if the measurement is also made within the reflective chamber. SPLs measured in the reverberant-field of the ear cannot directly be compared to SPLs in the free-field without first compensating for the higher SPLs at certain frequencies caused by the resonance of the ear canal.

Typically, noise and sound are differentiated only by the listener's preference. For example, loud music coming from a stereo system would generally be considered a desirable sound by the listener, but could be regarded as noise to an annoyed neighbor. In this study, the term noise was used to describe both industrial background noise and the sound output from PMPs. Although PMP output could also be considered music or sound rather than noise, because of the potential for hearing impairment from excessive PMP listening and the simplicity in relating the two distinct sound sources, the term noise was chosen to describe PMP output in this study.

Audition:

Audition, or the perception of sound, is accomplished via the complex transformation from sound pressure waves to electrical nerve impulses and interpretation in the brain. The human ear is divided into three main parts; the outer ear, the middle ear, and the inner ear (see Figure 2.1). The outer ear consists of the pinna (or auricle), which is the visible portion of the ear, the external auditory canal (or ear canal), and the tympanic membrane (or ear drum). The pinna serves to gather sound waves and direct them into the ear canal. The ear canal provides a constant air temperature and humidity for the sound waves to travel through and directs sound waves to the ear drum. The ear canal and pinna amplify sound wave frequencies between 2000 and 4000 Hz by as much as 10 to 15 dB. Thus, sounds in this frequency range appear louder and can be more damaging than lower or higher frequency sounds. Sound waves impact the ear drum and cause it to vibrate at a frequency and amplitude relative to the frequency and amplitude of the impinging sound wave.

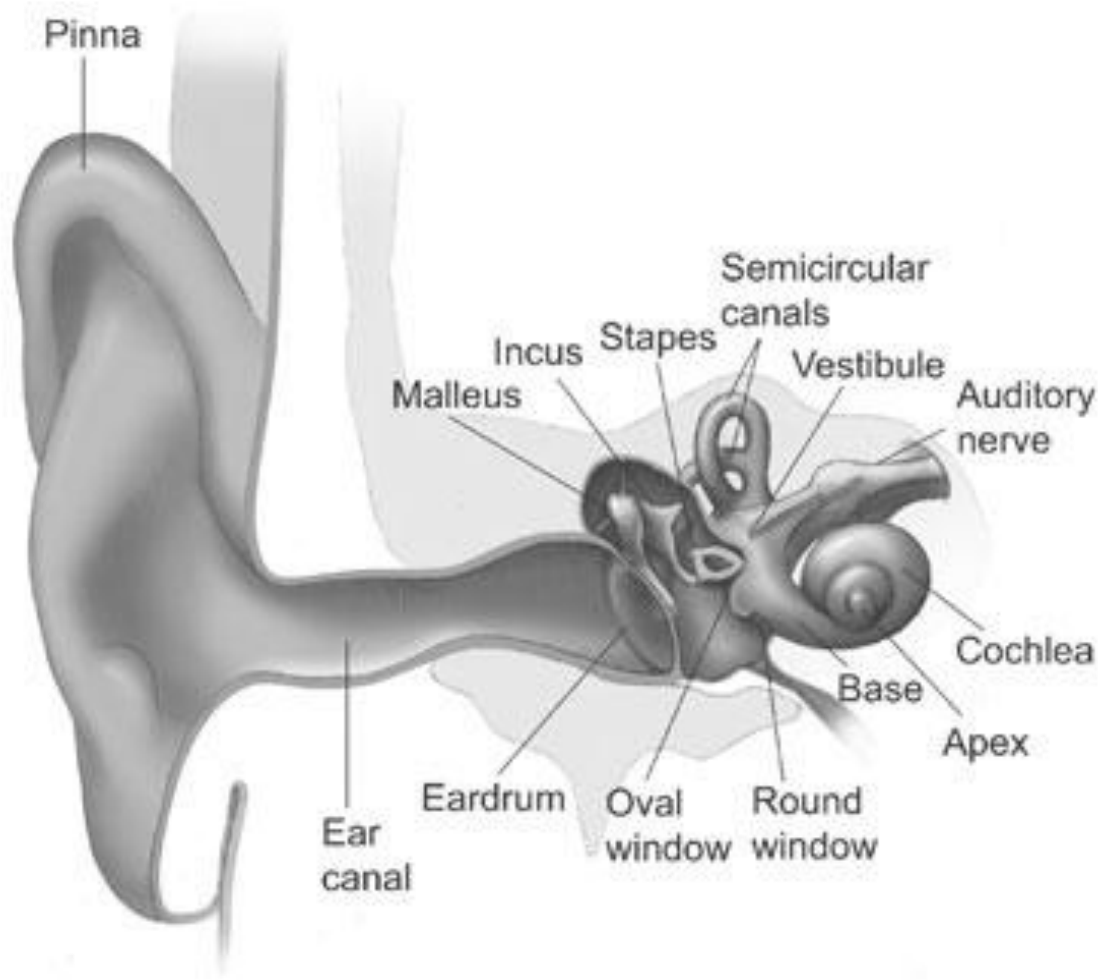

Figure 2.1: Structures of the Human Ear (NIDCD, 2008)

The middle ear is an air-filled chamber which begins at the inner membrane surface of the ear drum and ends at the oval window. Vibration of the ear drum caused by a sound pressure wave is transformed to a mechanical force via the lever action of three small bones; the malleus, incus, and stapes, which are collectively referred to as the ossicles. The mechanical force is ultimately transformed again to a fluid pressure wave as the foot of the stapes presses upon the oval window, which is the entry into the fluid filled inner ear. The conversion of energy from a pressure wave to a mechanical force and back again is not efficient, but the lever action of the ossicles provides sufficient mechanical advantage to overcome the energy decay and further amplify the signal. By the time a sound pressure wave in air has become a fluid pressure wave in the inner ear, the amplitude has increased by a factor of 15 (Smith, 1997).

The inner ear includes a convoluted, fluid filled, membrane-bound organ called the cochlea, which begins at the oval window and ends at the round window. Vibration of the oval window causes a pressure wave in the cochlear fluid which oscillates and causes vibration of the flexible basilar membrane. The vibration causes stereocilia topped receptor cells embedded into the basilar membrane to shear against an overhanging protrusion referred to as the tectorial membrane (see Figure 2.2). This shearing action causes the firing of nerve impulses which are delivered to the brain and interpreted as sound.

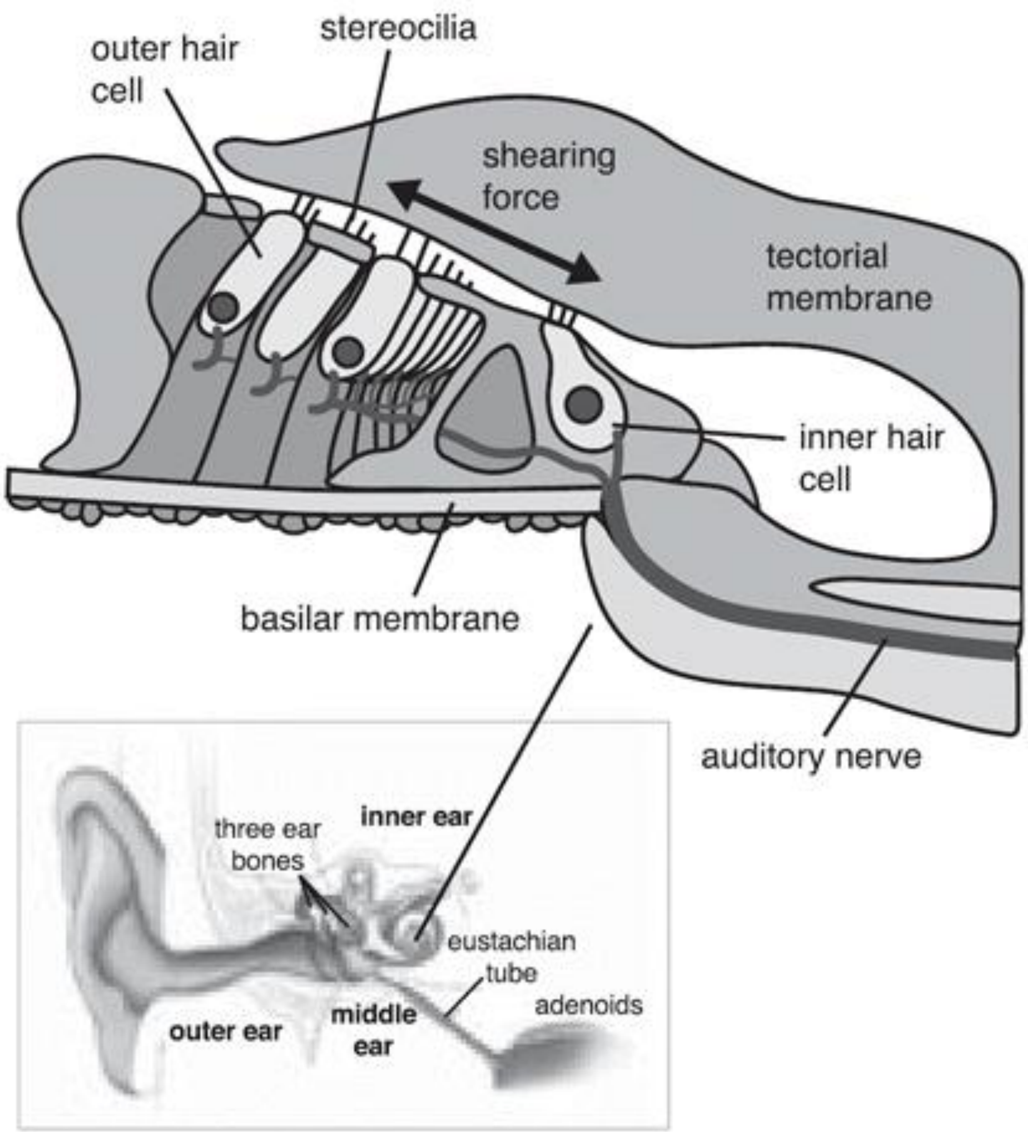

Figure 2.2 Shearing Interaction between Stereocilia and Tectorial Membrane in Response to Sound Inside the Cochlea (National Institutes of Health, 2007)

Noise-Induced Hearing Loss:

The beginning of the industrial revolution in the U.S. and in Europe marked the departure from an agricultural-based to an industrial-based labor force. As a result, workers became increasingly exposed to hazardous noise. Ramazzini first described the relationship between loud workplace noises and hearing impairment in 1713, by describing the relationship between the hammering of metal to hearing impairment and deafness in coppersmiths (Wright, 1940). Several early studies followed, whose authors also found a relationship between hearing impairment and other occupations; namely blacksmithing, change ringing, mining, and boiler-making (Berger, Royster, Royster, Driscoll, & Layne, 2003). Although the relationship between loud noises and hearing impairment was evident early in the industrial revolution, the mechanisms of action and prevention methods were not yet elucidated.

Following World Wars I and II, in which countless soldiers suffered hearing impairment, there was increased interest in investigating noise-induced hearing loss (NIHL). It was not until the 1950's that international efforts resulted in the development of standardized equipment and techniques for measuring noise and hearing impairment. Audiometry techniques were developed that measured subjects' ability to perceive varying pure-tone intensities to determine a frequency-specific threshold of hearing. A temporary threshold shift (TTS) is the increase in hearing threshold due to noise exposure, which is temporary and reversible upon removal from a noise exposure environment. A permanent threshold shift (PTS) is the irreversible increase in hearing threshold due to noise exposure. The development of a noise-induced TTS and PTS in an individual is the combined result of noise intensity, duration of exposure, and the frequency signature of the noise. Because the ear is more sensitive to different frequencies, prediction of NIHL was not possible using simple SPL dB measurements. The A-weighting network for use with SPL measurements (denoted as dBA) was developed as a simple method to de-rate sound frequencies to which the human ear is less sensitive, and to accentuate frequencies to which the human ear is most sensitive. Several studies have produced results that indicate the use of A-weighted SPLs is a reasonable approximation of hearing impairment hazard as compared to the frequency-specific damage response of the human ear (Botsford, 1967; Alexander Cohen, 1972). Prior to 1950, noise exposure recommendations considered only the intensity of noise exposures and not the duration. The relationship between the intensity and duration of noise exposures relies on the equal energy hypothesis, which states that for every 3 dB increase or decrease in SPL, there is a doubling or halving of sound energy, respectively. The equal energy hypothesis was first described in 1957 by Eldredge and Covell (1957). Most U.S. and international standards are based upon the equal energy hypothesis and specify the use of a 3 dB exchange rate. For every 3 dB increase in noise exposure, the allowable exposure time is cut in half and vice versa. However, the general acceptance of the equal energy hypothesis proceeded slowly and a small number of U.S. and international standards still utilize 4, 5, or 6 dB exchange rates, which are less protective and are based upon obsolete information.

Landmark NIHL studies in the 1960's and 70's measured the hearing ability and noise exposures of industrial-noise exposed workers and compared the results to low-noise exposed controls (Baughn, 1973; Passchier-Vermeer, 1968; Lempert & Henderson, 1973; Burns & Robinson, 1970). These studies provided much of the basis for the current hearing damage-risk criteria (DRC). Although there was not complete agreement between the NIHL studies, there was general consensus that noise levels above 85 dBA were capable of producing PTSs in a significant proportion of workers at one or more frequencies. Subsequent DRC studies have mostly analyzed the existing data sets from earlier studies to refine the DRC and develop standards that provide adequate protection against NIHL. A major determinate for deciding what noise exposure level and duration limits are adequately protective is the decision regarding acceptable hearing impairment. Typically, PTSs at speech intelligibility frequencies (500 – 4000 Hz) are considered the most detrimental to functionality and quality of life. Initial definitions of hearing handicap required an average hearing threshold increase of 25 dB at 500, 1000, and 2000 Hz (American Academy of Otolaryngology, 1961). However, the results of later studies suggested that 3000 and 4000 Hz frequencies are also important for speech intelligibility and should therefore be considered (Johnson, 1973; Burns & Robinson, 1970). Methods are also available to delineate between hearing threshold increases caused by noise exposures and those increases caused by presbycusis (sensorineural hearing loss due to aging alone).

Relevant Standards:

There are many standards that address occupational noise exposures in the U.S.; specifically those published by OSHA, NIOSH, The American Conference of Governmental Industrial Hygienists (ACGIH), and the U.S. Military. OSHA regulates hazardous occupational noise exposures for general industry and construction in the U.S. OSHA requires protection, in the form of feasible engineering and/or administrative controls, and personal protective equipment (PPE), for noise levels above the permissible exposure limit (PEL) of 90 dBA, eight-hour TWA (OSHA, 1983). OSHA also requires a hearing conservation program (HCP) when noise levels exceed the action level of 85 dBA, eight-hour TWA (OSHA, 1983). A HCP details employer requirements to conduct noise monitoring and provide workers with hearing protections devices (HPDs). In addition, employers are required to provide education on the effects of hazardous noise, training on the selection and fit of HPDs, and annual hearing tests (OSHA, 1983). OSHA requires that noise levels be measured using a SLM or personal noise dosimeter with an A-weighting filter, slow integrating response, 5 dB exchange rate, and a measurement threshold of 90 and 80 dBA for comparison to the PEL and action level, respectively.

NIOSH and ACGIH standards are published as recommendations and do not have a regulatory basis. However, NIOSH and ACGIH standards are more protective against ONIHL. Both NIOSH and ACGIH recommend an occupational noise exposure limit of 85 dBA eight-hour TWA (ACGIH, 2007; NIOSH, 1998). NIOSH and ACGIH recommend that noise levels be measured using a SLM or personal noise dosimeter with an A-weighting filter, slow integrating response, 3 dB exchange rate, and a measurement threshold of 80 dBA. The lower exposure limit, threshold level, and exchange rate in the NIOSH and ACGIH standards are more protective because lower sound energy is needed to reach the exposure limit. NIOSH and ACGIH exposure limits are identical, but the NIOSH standard includes additional recommendations regarding program administration. Most U.S. Military and international occupational noise exposure standards have also adopted an 85 dBA eight-hour TWA exposure limit using a 3 dBA exchange rate, which is consistent with general scientific consensus regarding occupational noise DRC.

Relevant Studies:

Recently, there has been increased concern about exposure to leisure noise contributing to noise-induced hearing loss (Clark, 1991; Dalton & Cruickshanks, 2001), including the use of PMPs (Clark, 1999; Fligor & Ives, 2006). PMPs include electronic media devices such as the Apple iPod and other portable MP3 players; portable CD players; and personal computers and cellular phones that can double as PMPs when coupled with a headset. In addition, there has been concern about the use of different PMP headsets that are placed in the auricle or ear canal while delivering music to the listener's ears. It has been shown that earbud headphones can increase the level of sound delivered into the ear canal by seven to nine decibels on the A-weighted scale (dBA) as compared to other types of earphones (Fligor & Cox, 2004). It was reported that PMP users that use "sound isolation earphones" do not increase their chosen listening levels in "loud environments" to the same level as those using other types of earphones (Fligor & Ives, 2006). Thus, the type of headsets that a user chooses may influence the chosen sound listening level and noise energy delivered to the ear, especially if used in the workplace to drown out other occupational noise exposures.

It was estimated in 2005 that 22 million American adults own MP3 players or iPods (Rainie & Madden, 2005) and as of April 9, 2007, 100 million iPods had been sold (Apple Computer, Inc., 2007). While there is growing concern about the use of PMPs and hearing loss, there are few studies examining this association and the results have been conflicting (Catalano & Levin, 1985; LePage & Murray, 1998; Meyer-Bisch, 1996; Williams, 2005; Wong, Van Hasselt, Tang, & Yiu, 1990). Recent marketing research articles report that one in five people under the age of 30 own a portable MP3 player, and that this number is growing (Rainie & Madden, 2005).

Hearing impairment risk from PMP use depends on the duration of hazardous sound exposure, chosen listening level, individual susceptibility, and non-PMP noise in the environment (Clark, 1999). Fligor and Ives (2006) reported that in "quiet environments" 6% of subjects chose listening levels greater than 85 dBA and in "loud environments" 80% of PMP users with iPod earbud headsets or Koss over-the-ear headsets listened at sound levels greater than 85 dBA. Williams (2005) reported that the mean listening time to PMPs per day in non-occupational environments was 2.38

hours (n = 55). However, Portnuff and Fligor (2006) recently reported that with improved technology, increased battery life, and greater music storage, PMP users could listen for longer periods as compared to PMP usage in the past. Thus, users may be able to extend their PMP use at work and at home. In the 1980's, Katz, et al. (1982) selected three portable stereos and measured the sound output using an artificial ear and SLM. They found that the range of sound output at volume setting "4" was 93 to 108 dBA and that a volume setting "8" exceeded 115 dBA. They concluded, "There can be no doubt that these units have the potential for inducing a permanent bilateral sensorineural hearing loss." In addition, Catalano and Levin (1985) used the OSHA criterion of greater than 90 dBA as a level of "unacceptable" noise for exposure from portable stereos. They found from a sample of 154 college students that 41.2% of males and 29.2% of females exceeded the 100% dose set by OSHA [90 dBA eight-hour TWA] while listening to their PMPs at their chosen listening levels. Further, they found that 10.1% of these subjects experienced a 400% dose or an eight-hour TWA of 100 dBA. Given these output levels and those measured by others (Catalano & Levin, 1985; Fligor & Cox, 2004; Katz, Gerstman, Sanderson, & Buchanan, 1982) PMP users can exceed a TWA of 85 dBA within minutes or hours depending upon their chosen listening level. Portnuff and Fligor (2006) suggested a listening level "speed limit" of 80% volume setting for 90 minutes per day for most headset and PMP combinations. However, the speed limit recommendation may not be practical for workplace PMP use, where duration of use and background noise levels may make it difficult for workers to adhere to this recommendation.

Rice, et al. (1987) measured the mean sound output levels of personal cassette players that were set at the subjects' chosen listening levels in a laboratory and street setting and found that 25% of the study population had set it to levels of at least 90 dBA and 5% at levels greater than 100 dBA. Additionally, they found that listeners set the volume in a relatively quiet area at a mean level of 80.7 dBA but set it to 85.1 dBA when background noise (70 dBA) was present. Turunen-Rise, et al. (1991) measured the sound output levels of personal cassette players, and then had six subjects listen to the personal cassette players for one hour. The subjects were tested for a temporary threshold shift in hearing. They reported that "exposure levels for the great majority of personal cassette player users were below noise levels which cause noise-induced hearing loss." More recently, Williams (2005) measured the sound levels of PMPs by soliciting participation from 55 PMP users who were walking in a suburban area to ensure that he captured "real-life" PMP sound levels. He found that sound levels ranged from 73.7 dB to 110.2 dB with a mean sound level of 86.1 and a mean background noise level of 73.2 dB. Similarly, Serra, et al. (2005) measured chosen PMP sound levels used by adolescents from 75 dB to 105 dB. Wong, et al. (1990) measured the preferred chosen listening levels of PMPs and found the range of sound levels for rock music was 58.6 to 116 dBA (mean of 71.2 dBA) and for light music a range of 56 to 113 dBA (mean of 69.5 dBA).

Meyer-Bisch (1996) examined the effects that PMPs had on hearing thresholds and concluded that when listening for more than eight hours per week, subject hearing thresholds (n=54) were significantly higher (indicating hearing loss) than a control group. Additionally, LePage and Murray (1998), using a cross-sectional design including over 1700 subjects, reported that otoacoustic emissions from the ear were significantly lower (indicating hearing damage) in PMP users versus non-PMP users. They concluded, "The use of PMP headsets…is associated with rapid aging of the cochlea comparable with industrial noise trauma." In contrast, Williams (2005), using a cross-sectional design, did not observe a correlation between the use of PMPs and self-reported hearing loss in a study of 55 individuals. Hodgetts, Szarko, and Reiger (2009) examined the effects of background noise at rest and during exercise on personal listening levels of PMP users and found that 33% to 42% of participants may be exposed to doses in excess of occupational exposure limits when calculated using self-reported exposure durations (n=24).

Many PMP studies have compared measured chosen listening level outputs to noise exposure standards to determine if PMP use could contribute to NIHL. However, the evaluation of PMP headset output involves measuring the output level inside of the ear canal, which is a reverberant field. Such measurements are accomplished by attaching a headset to an ear simulator, with a microphone coupler placed at the terminus of the ear canal where the tympanic membrane would normally be located. A transfer function must be applied to reverberant field noise measurements to produce free-field equivalent levels that can be compared to existing noise exposure standards, which are also based upon free-field measurements (Hammershøi & Møller, 2008). The results of early studies that measured the output levels of older portable stereos, as well as some contemporary studies that measured modern PMPs, are not directly comparable to occupational exposure limits because the levels were measured in the reverberant field and the results were not transformed to free-field equivalent levels (Katz, Gerstman, Sanderson, & Buchanan, 1982; Lee, Senders, Gantz, & Otto, 1985; Torre, 2008; Hodgetts, Szarko, & Rieger, 2007). Further, the DRC used for industrial noise exposures and ONIHL may not be applicable to the DRC for music exposures (Strasser, Irle, & Legler, 2003). Skrainar, Royster, Berger, & Pearson (1987), in the only occupational study examining portable radio use in the workplace, found a negligible increase in the mean ONIHL risk of workers who used portable radios compared with those who did not. However, the authors noted that one third of the subjects who used portable radios would exceed the OSHA PEL if they listened for eight hours per day (Skrainar, et al., 1987). Given the changing PMP technology and conflicting results of previous studies, the results of this study provide important new evidence concerning PMP output and potential overexposure to noise in the workplace.

CHAPTER 3: PURPOSE AND SCOPE

Purpose:

Occupational PMP use poses unique challenges for health practitioners, specifically the evaluation of headset output and the determination of ONIHL risk. Anecdotal evidence suggests that there are many workers in a variety of occupational sectors who use PMPs while on the job. In accordance with NIOSH's National Occupational Research Agenda, this research determined if workers were being exposed to hazardous levels of noise in the workplace by using PMPs. This study provided necessary data to determine if a prospective epidemiological study, that includes the measure of hearing loss over time, is warranted to ascertain if PMP use in the workplace is a contributing factor to occupational noise-induced hearing loss (ONIHL).

Evidence from studies that examined non-occupational PMP use suggests that background noise level may be correlated with PMP listening level. Thus, workers exposed to high-background noise levels would likely listen at higher volumes than workers exposed to low-background noise levels. The purpose of this study was to determine the noise exposures of workers who use PMPs during work in high- and low-background noise environments.

Research Hypothesis and Specific Aims:

The research hypothesis for this study is that noise from PMPs contributes to worker overexposure to noise as compared to published occupational exposure limits. The objective for this research is to determine if workers are exposed to hazardous levels of noise because of PMP use in the workplace. The study rationale is that health practitioners can use the outcomes to educate the workforce in controlling noise exposure and preventing hearing impairment. In addition to testing the research hypothesis, the following three specific aims have been addressed for this study:

1. Measure and evaluate the chosen sound-output levels from the use of PMPs in the workplace.
2. Determine if workers are overexposed to noise from using PMPs.
3. Evaluate the relationship between sound-output levels of PMPs to background workplace noise.

Scope:

Workers at a Colorado manufacturing facility were solicited for participation in this research. The manufacturing facility was selected because the employer permits the indiscriminate use of PMPs by virtually all personnel. The facility employs workers in high-background noise exposure production work areas and in low-background noise exposure office/administrative work areas. All workers within specific high- and low-background noise exposure areas were questioned about workplace PMP use. Those workers who indicated regular PMP use were solicited for participation in this study. Workers were evaluated for background noise exposure levels, PMP listening levels, and PMP use behaviors. Evaluations at the facility were completed on four different workdays between September 27, and November 5, 2010. Evaluation days at the facility were chosen based upon the time constraints imposed by facility management and volunteers, and the availability of the investigators. The research evaluation schedule is provided in Table 3.1.

Table 3.1: Research Evaluation Schedule, by Background Noise Exposure Category and Work-Shift

Evaluation Date	**Noise Exposure Category**	**Work-Shift**
September 27, 2010	High	Day
October 6, 2010	High	Day
October 22, 2010	High	Night
November 5, 2010	Low	Day

CHAPTER 4: MATERIALS AND METHODS

Site Selection:

An employer of workers at a manufacturing facility that permitted the use of PMPs by workers in industrial and office work environments was identified in Colorado by the researcher through personal acquaintance. The facility's Environment, Safety, and Health Department management was contacted to solicit support for this research. After the research purpose, scope, confidentiality measures, recruitment, and voluntary participation of employees were explained; facility management indicated their willingness to participate in the research and their interest in receiving information regarding the noise exposures of workers who use PMPs. All contact with the facility and its employees was made in accordance with procedures approved by the Colorado State University (CSU) Institutional Review Board (IRB) and the Research Integrity and Compliance Review Office.

Questionnaire Development:

A questionnaire was developed to ascertain worker PMP use behaviors as well as basic demographic and job information (see Appendix A). The development process for validation and verification of the study questionnaire was derived from recommendations provided in the U.S. General Accounting Office guidance document, *Developing and Using Questionnaires* (GAO/PEMD, 1993). An initial questionnaire draft was designed and submitted for validation via expert review by two Certified Industrial Hygienists who specialize in occupational noise exposure evaluation and noise exposure research with human subjects. The reviewers were asked to evaluate the initial questionnaire draft and answer the following questions:

1. In your expert opinion, are the questions and the manner in which they are asked adequate to answer the study objectives AND specific aims?
2. In your expert opinion, does the target population have the necessary knowledge to answer the questions?
3. In your expert opinion, do the questions include the appropriate content for the variables we are attempting to measure with this study?

The questionnaire was revised to reflect the changes recommended by the expert reviewers. The questionnaire draft was then administered to seven workers at CSU to determine if any questions were difficult to understand or took excessive time to answer. No questions posed any apparent difficulty for the CSU workers, thus the questionnaire draft was finalized for use in this study.

Questionnaire data were verified by crosschecking responses regarding workplace PMP use behaviors with the facility's Environment, Safety, and Health Department management and staff. In addition, questionnaire data were keyed twice into electronic storage to ensure the accuracy of keyed data prior to analysis. No formal pre-test of the questionnaire was conducted nor were reliability measures taken prior to the use of the final questionnaire.

Identification and Recruitment of Potential Subjects:

Potential research subjects were identified based upon whether they worked in either high- or low-background noise areas in the facility. The facility was divided into two production buildings, Plant A and Plant B. Personnel who worked on the production floor of either plant were identified for potential recruitment as high background-noise-exposed (HBNE) workers. The facility also provided quiet work areas for office/administrative personnel. Personnel who worked in two large, shared office work areas were identified for potential recruitment as low background-noise-exposed (LBNE) workers. The two large office work areas were identified as Office A and Office B. Production in Plant A and Plant B operated on a 24-hour cycle, supported by a two-shift staggered work schedule for production floor personnel. Conversely, office/administrative personnel worked only during a single shift.

All personnel identified for potential recruitment that had either high- or low-background noise exposures were permitted by facility management to use PMPs at their own discretion and were eligible for recruitment provided that they chose to use PMPs during work. Each HBNE worker in Plant A and Plant B was asked if they used PMPs during work, a 'yes' response qualified them for recruitment into the study. Workers who indicated that they use PMPs during work were read an IRB-approved recruitment script explaining the rights, responsibilities, and expectations of potential subjects. Subjects who agreed to volunteer provided informed consent and received a copy of the informed consent document. The recruitment process was repeated during the day and night shifts for HBNE workers in Plant A and Plant B and during the day shift for LBNE workers in Office A and Office B. Facility management was consulted to verify that the investigators contacted each employee scheduled to work in the identified high- and low-background noise work areas. All subject recruitment, interviews, and measurements took place at the manufacturing facility between September 27, and November 5, 2010.

Interview and Data Collection:

Questionnaire items were read aloud to subjects by an interviewer who recorded subject responses on the Questionnaire and Data Sheet. Information for reproduction of the study was also collected; specifically the worker task performed during measurement; subject PMP and headset device details; music/sound file name and artist; and approximate volume setting of the PMP. The interviewer also recorded the type of noise attenuation, if any, of the subject's headset. Tightly fit, molded canalphones (earphones that are inserted into the ear canal) and circumaural headsets (headphones that surround the pinna) that fully encompassed the ear were classified as 'passive noise isolating' provided they did not have active noise cancelation capability. Supra-aural (headphones that rest on the pinna) and earbud headphones (earphones that rest in the ear at the opening of the ear canal) without active noise cancelation capability were classified as 'no noise attenuation'. Active noise cancelling headsets with the option to toggle the active noise cancelation feature were checked to make sure the active noise cancelation feature was turned on. If the noise-cancelling feature was turned off, the headset was classified as either passive noise isolating or no noise attenuation, depending upon the style and fit of the headset.

Background Noise Measurement:

A Quest Technologies/Metrosonics db-3080, type two, Sound Level Meter (SLM) was used to measure background noise levels for HBNE and LBNE workers.

The SLM was pre- and post-calibrated using a Quest Technologies/Metrosonics cl-304 Acoustic Calibrator. The SLM measurement settings and specifications are summarized in Table 4.1.

The equivalent, continuous A-weighted sound pressure level (L_{Aeq}) was measured by briefly removing the subject from her/his workstation and positioning the SLM microphone at the location normally occupied by the subject's head, while pointing the microphone toward the noise source at approximately 70-90 degrees incident to the noise source. The background L_{Aeq} was measured for two minutes.

Work-shift personal noise dosimetry was also conducted to measure the work-shift L_{Aeq} of all HBNE subjects to account for the potential variability in noise exposure throughout the workday. Larson Davis, type two, Personal Noise Dosimeters 706rc and 703+ were used to measure the work-shift L_{Aeq}. The dosimeters were pre- and post-calibrated using a Larson Davis CAL 150 Acoustic Calibrator. Dosimeter microphones were clipped to subjects' shirts between the collar and shoulder on the side of the body with the highest noise exposure. The dosimeters were clipped to subjects' belt or pants and the excess cord was secured with tape. Subjects were instructed not to blow on, yell into, or intentionally bump the microphone during sampling. Work-shift L_{Aeq} measurements were collected and recorded for subjects on the same day that PMP listening levels and background noise levels of subjects were measured. The dosimeters' measurement settings and specifications are summarized in Table 4.1.

<u>PMP Listening Level Measurement:</u>

A G.R.A.S. Sound and Vibration Right Ear and Cheek Simulator Type 43AG (ear simulator), connected to a Larson Davis System 824 SLM/Octave Band Analyzer for data acquisition, were used to measure the PMP headset output levels for HBNE and LBNE workers. The ear simulator was calibrated using a Larson Davis CAL 200 Acoustic Calibrator. The ear simulator measurement settings and specifications are summarized in Table 4.1.

Table 4.1: Instrument Settings and Specifications for the SLM and Ear Simulator

Parameter	SLM	Ear Simulator	Dosimeters
	Setting / Specification	Setting / Specification	Setting / Specification
Exchange Rate	3 dB	3 dB	3 dB
Exponential Averaging	Slow	Slow	Slow
Frequency Weighting	A Weighting	Un-weighted	A Weighting
Measurement Range	40 – 140 dB	48 – 128 dB	40 – 143 dB
Threshold	80 dB	80 dB	80 dB

A small cart was used to transport the ear simulator to the subjects' work areas. Subjects were asked to remove their headsets without adjusting the volume setting of their PMP. The PMP was paused, and the headset connector was removed from the subject's PMP. The subject's headset connector was then inserted into the researcher's PMP that had been pre-loaded with a pink noise stationary test signal. The subject's right earpiece and the ear simulator were then cleaned with an alcohol swab and allowed to dry. The test signal was started, and the researcher's PMP was set to maximum volume. The first measurement series recorded a measurement of both the background equivalent continuous un-weighted sound pressure level (L_{eq}) and the un-weighted 1/3 octave band frequency spectrum through the open ear simulator. The subject's right headset earpiece was then fit into (for canalphones and earbuds) or onto (for supra-aural and circumaural headsets) the ear simulator. The right earpiece was fit by adjusting the earpiece while monitoring the sound pressure level output. Best fit was determined when the output showed a high and stable reading, as described by Berger, Megerson, and Stergar (2009). An adjustable force clamp was applied to the right earpiece of supra-aural and circumaural headsets during fitting. The headset connector was then removed from the researcher's PMP and inserted back into the subject's PMP. With the subject's PMP still paused, a second measurement series recorded the L_{eq} and the un-weighted 1/3 octave band frequency spectrum through the ear simulator coupled with the fitted earpiece. The first and second measurement series (the ear simulator open and the ear simulator fit with the subject's earpiece) were recorded for HBNE and LBNE subjects to provide an estimate of earpiece attenuation. The subject's PMP was then un-paused, and the third measurement series recorded the PMP listening level L_{eq} and the un-weighted 1/3 octave band frequency spectrum. The subject's PMP listening level was measured for two minutes.

Subjects' PMP listening levels were measured and then converted to free-field equivalent A-weighted sound pressure levels (FFL_{Aeq}) for comparison to occupational exposure limits in accordance with the International Organization of Standardization (ISO) Standard 11904-2:2004 (ISO, 2004). The conversion to FFL_{Aeq} was accomplished by taking the measured un-weighted 1/3 octave band frequencies between 20 and 10,000 Hz and subtracting a frequency specific transfer function from each 1/3 octave band, as described in ISO 11904-2:2004 (ISO, 2004). The differences were then summed and A-weighted to produce the FFL_{Aeq}, which are comparable to traditional free-field noise exposure measurements and occupational noise exposure limits. A picture of the ear simulator is provided in Figure 4.1.

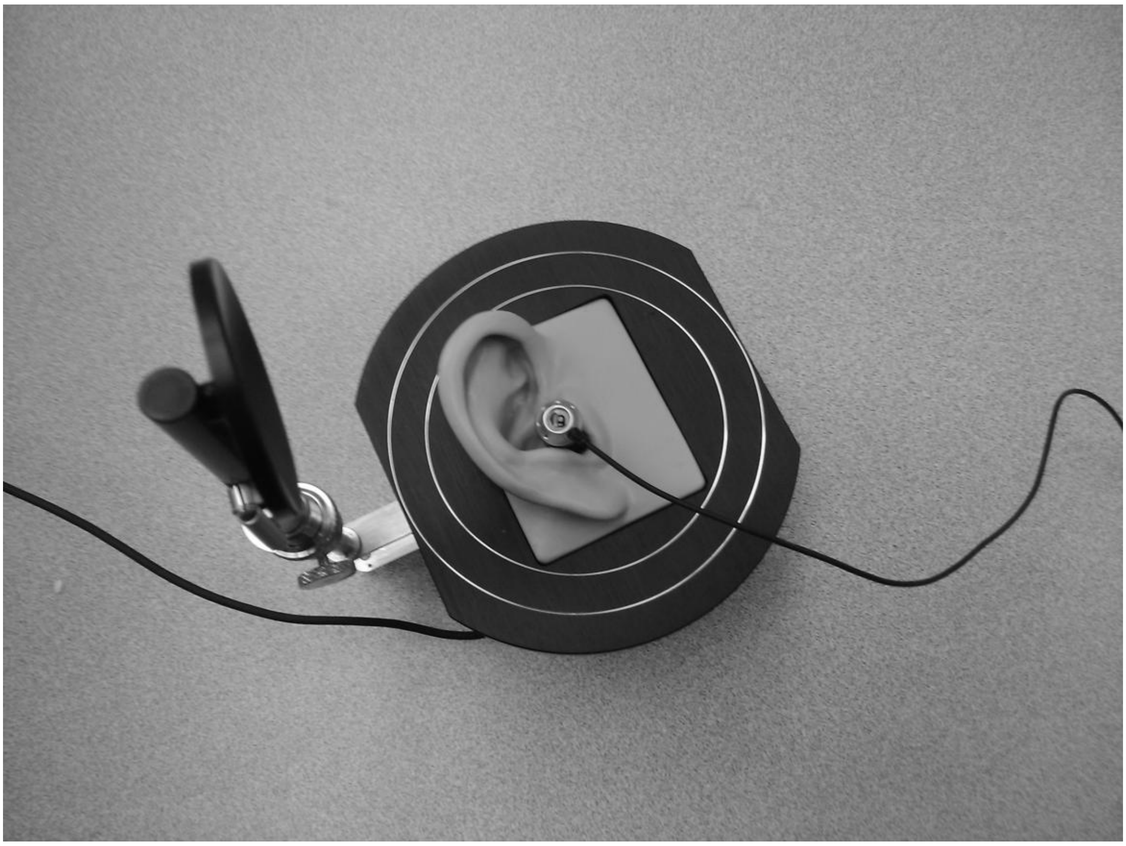

Figure 4.1: Photograph of Ear Simulator Coupled with a Canalphone Headset

Noise Exposure Estimation:

An estimate of occupational percent noise dose was calculated by adding the self-reported duration of workplace PMP use over the allowable exposure time permitted at the subjects' PMP listening level, to the shift length minus the self-reported duration of workplace PMP use over the allowable exposure time permitted at the background noise level (see Equation 4.1). The percent noise dose calculations using NIOSH and ACGIH occupational exposure standards are provided in Equations 4.1, 4.1.1, and 4.1.2. The percent noise dose estimates were then converted to a nominal eight-hour TWA for NIOSH and ACGIH criteria. The conversion from dose percent to a nominal eight-hour TWA for NIOSH and ACGIH criteria was accomplished by performing the calculation described in Equation 4.2. OSHA exposure estimates were not performed because OSHA regulations require that noise be measured using a 5 dB exchange rate. Because the ISO 11904-2:2004 method specifies only the use of a 3 dB exchange rate, the measurements should not be used to calculate exposures using OSHA criteria.

Equation 4.1: Occupational Percent Noise Dose

$$\text{Dose Percent} = \frac{C_L}{T_L} + \frac{C_B}{T_B} * 100$$

Where, C_L=Self-Reported Listening Time
C_B=Background Exposure Time=Shift Length- Self-Reported Listening Time
T_L=Allowable Exposure Time at FFL_{Aeq} Listening Levels, as Determined by Equation 4.1.1
T_B=Allowable Exposure Time at Background L_{Aeq} Levels, as Determined by Equation 4.1.2

Equation 4.1.1: Allowable Exposure Time at Background L_{Aeq}

$$T_B = 2^{\frac{8\text{ hours}}{\frac{L_{Aeq} - CR}{ER}}}$$

Where, CR=Criterion Level for NIOSH and ACGIH (85 dBA) Standards
ER=Exchange Rate for NIOSH and ACGIH (3 dBA) Standards
T_B=Allowable Exposure Time at Background L_{Aeq} Level

Equation 4.1.2: Allowable Exposure Time at FFL_{Aeq} Listening Level

$$T_L = 2^{\frac{8\text{ hours}}{\frac{FFL_{Aeq} - CR}{ER}}}$$

Where, CR=Criterion Level for NIOSH and ACGIH (85 dBA) Standards

ER=Exchange Rate for NIOSH and ACGIH (3 dBA) Standards
T_L=Allowable Exposure Time at FFL_{Aeq} Listening Levels

Equation 4.2: Conversion from Dose Percent to Eight-hour TWA

$$8\text{ Hour TWA} = \left(\frac{\text{ER}}{\text{Log}_{10}(2)}\right) * \text{Log}_{10}\left(\frac{\text{D}}{100}\right) + \text{CR}$$

Where, CR=Criterion Level for NIOSH and ACGIH (85 dBA) Standards
D=Occupational Percent Noise Dose as Calculated using Equation 4.1
ER=Exchange Rate for NIOSH and ACGIH (3 dBA) Standards

<u>Example Equations:</u>

The NIOSH and ACGIH eight-hour TWA for a subject with a FFL_{Aeq} listening level of 86 dBA, a self-reported listening time of 4 hours, a background L_{Aeq} level of 81 dBA, and a shift length of 10 hours would be calculated as follows:

Criterion Level (CR) = 85 dBA

Exchange Rate (ER) = 3 dBA

Allowable Exposure Time at Background Level (T_B) = $\frac{8\text{ hours}}{2^{\frac{81\text{ dBA} - 85\text{ dBA}}{3\text{ dBA}}}}$ = 20.2 hours

Allowable Exposure Time at Listening Level (T_L) = $\frac{8\text{ hours}}{2^{\frac{86\text{ dBA} - 85\text{ dBA}}{3\text{ dBA}}}}$ = 6.3 hours

Self-Reported Listening Time (C_L) = 4 hours

Background Exposure Time (C_B) = 10 hours – 4 hours = 6 hours

Occupational Percent Noise Dose (D) = $\frac{4}{6.3} + \frac{6}{20.2} * 100$ = 93.2 %

Eight-Hour TWA = $\left(\frac{3\text{ dBA}}{\text{Log}_{10}(2)}\right) * \text{Log}_{10}\left(\frac{93.2\ \%}{100}\right) + 85\text{ dBA}$ = 84.7 dBA

Data Analysis:

SLM and ear simulator measurement data were recorded on the Questionnaire and Data Sheet and saved to instrument memory. Measurement data were then downloaded from the instruments onto a computer and compared to the hand-recorded data for consistency. Questionnaire and Data Sheet responses were keyed twice into a Microsoft Excel spreadsheet and compared to ensure the integrity of data entry. Simple calculations involving sample population demographic information, PMP use behaviors, and subject device information were performed in Microsoft Excel. Earpiece attenuation estimates were calculated by subtracting the FFL_{Aeq} measured through the open ear simulator (i.e., not coupled with an earpiece) from the FFL_{Aeq} measured through the ear simulator coupled with a subject's quiet earpiece (i.e., without media output playing).

All data analyses were conducted using SAS on Demand for Academics, Enterprise Guide version 4.2. Several specific tests were used to evaluate the data and answer the original research questions. A Two-Sample T-Test was conducted to compare the mean FFL_{Aeq} of HBNE and LBNE workers. Prior to data collection, a preliminary power analysis of this test was conducted using data from a 2009 Hodgetts, et al. study that compared the chosen recreational listening levels of people in high- and low-background noise environments, while at rest and during exercise (Hodgetts, Szarko, & Reiger, 2009). It was estimated that a sample size of 11 would provide 93 percent power for this study.

A Paired T-Test was conducted to compare the mean background L_{Aeq} and the mean work-shift L_{Aeq}, as measured with the SLM and dosimeters respectively. Because FFL_{Aeq} and L_{Aeq} were measured in the logarithmic decibel scale, the signal-to-noise ratio for each subject was calculated by subtracting L_{Aeq} from FFL_{Aeq}. The signal-to-noise ratio is important because it describes how loudly subjects listened to their PMPs to mask background noise. A Paired T-Test was conducted to compare the signal-to-noise ratios by high- and low-background noise exposure category and by headset noise attenuation category. A One-Sample T-Test was also conducted to compare subjects' occupational noise exposure estimates to occupational exposure limits. The assumptions of normality and equal variance for the various T-Tests were also tested. Normality was tested using the SAS Univariate Procedure normality test series, which specifically includes the Shapiro-Wilk W, Kolmogorov-Smirnov D, Anderson-Darling A2, and Cramer-von Misers W2 tests. Assumptions of equal variance were tested using both the Folded F-Test and Levene's Test. If all of the tests failed to reject the null hypotheses, then the assumptions of equal variance and normality were considered to be supported. On the other hand, if any test rejected any null hypothesis of equal variance or normality, then data transformations or non-parametric alternatives were considered.

CHAPTER 5: RESULTS AND DISCUSSION

Sample Population:

A total of 24 subjects, 12 HBNE and 12 LBNE, were selected for evaluation in this study. Fifty-three total employees were working in production areas in Plant A and Plant B during both the day and night shifts on the sampling days. Twelve of the 53 (22.6%) HBNE workers indicated that they used PMPs while working and all 12 agreed to participate in this study. Thirty total employees were working in low-background noise areas in Office A and Office B during the day shift on the sampling day. Twelve of the 30 (40%) LBNE workers indicated that they used PMPs while working and agreed to participate in this study. Two of the 30 (6.7%) office/administrative workers refused to participate in this study and did not indicate whether or not they used PMPs during work. The observed proportions of PMP use by HBNE and LBNE workers were lower than the initial estimates provided by facility management of 30% and 50% PMP use for high- and low-background noise exposure areas, respectively. However, the facility's Environment, Safety, and Health Department management corroborated the findings by indicating that the workers observed using PMPs in office/administrative and productions areas were consistent with their own observations. Of subjects in the HBNE areas, 11 of 12 (91.7%) subjects were male and 1 of 12 subjects (8.3%) was female. Of subjects in the LBNE areas, 6 of 12 (50%) subjects were male and 6 of 12 (50%) subjects were female. The mean age of both HBNE and LBNE subjects was similar, specifically 34.4 years and

36.3 years, respectively. The average shift length,excluding the lunch period, for HBNE and LBNE subjects was 10.5 hours and 8.8 hours, respectively. Six of 12 (50%) HBNE subjects worked during the night shift. The sample population in both HBNE and LBNE areas was predominantly Caucasian. However, race and ethnicity were not considered for analysis in this study. There were insufficient numbers of subjects who reported each media type for statistical analysis by media category. Media type and other data collected for reproducibility purposes are not included in these results. A summary of sample population characteristics is provided in Table 5.1.

Table 5.1: Sample Population Characteristics

Characteristic	High-Background Noise	Low-Background Noise
Number of Subjects	12	12
Mean Subject Age	34.4 years	36.3 years
Male to Female Ratio	11:1	1:1
Mean Shift Length	10.5 hours	8.8 hours

PMP Listening Behaviors:

Subjects were questioned about details regarding their PMP use. The mean self-reported workplace PMP listening time for HBNE subjects was 3.9 hours per day, and ranged from 0.75 to 9 hours. The mean self-reported workplace PMP listening time for LBNE subjects was 3.4 hours per day, with a range of 1 to 5.5 hours. Mean workplace listening times for both subject exposure categories were compared with a two-sample T-Test and were not significantly different (p-value=0.5051). The assumptions of normality and homogeneity of variance were met for workplace listening times of HBNE and LBNE subjects. The combined mean workplace listening time was 3.6 hours per day. The proportion of time spent listening to PMPs at work was approximately the same with averages of 37% and 38% of the mean work-shift spent listening to PMPs for HBNE and LBNE subjects, respectively. HBNE subjects reported a mean PMP listening time of 0.76 hours per day recreationally (i.e., outside of work), including before and after work-shifts and on days off. LBNE subjects reported a mean recreational PMP listening time of 0.89 hours per day. Recreational listening times were calculated by first adding the product of number of days worked and the reported listening time before and after work, to the product of number of days off and the reported listening time on days off. The sum was then divided by seven days to give the average daily recreational listening time for each subject.

Surprisingly, 11 of 12 (91.7%) of LBNE subjects reported listening to PMPs at work to drown out background noise, compared to only 6 of 12 (50.0%) of HBNE subjects. All LBNE subjects (12 of 12) reported listening to a PMP at work for more than five years. Six of twelve (50%) of HBNE subjects reported workplace listening for more than five years, 3 of 12 (25%) for two to five years, and 3 of 12 (25%) for less than two years. A summary of the sample population PMP listening behaviors is provided in Table 5.2.

Table 5.2: Subject PMP Listening Behaviors by Background Noise Exposure Category

Exposure Category	Daily Workplace Listening Time	Proportion of Work-shift Spent Listening	Daily Recreational Listening Time	Proportion Using PMPs to Drown Out Noise	Proportion Using PMPs at Work Less than 5 Years
High-Background Noise (n=12)	3.9 Hours	37%	0.76 Hours	50%	0%
Low-Background Noise (n=12)	3.4 Hours	38%	0.89 Hours	92%	50%

PMP Device Information:

Information about the types of PMPs and the headsets that the subjects used was gathered during PMP listening level measurements. LBNE workers exclusively chose to listen to media via computer-based PMPs because their work involved sitting at a computer workstation. Conversely, HBNE subjects exclusively chose portable PMPs. Eight of 12 (66.7%) HBNE workers used MP3 player PMPs, while 4 of 12 (33.3%) used cellular phone based PMPs. HBNE workers were much more likely to select headsets with some form of noise attenuation as compared with LBNE workers. Nine of 12 (75.0%) HBNE subjects used headsets that had either passive or active noise-attenuating features. Three of 12 (25.0%) HBNE workers used circumaural headsets with active noise cancelation. Six of 12 (50.0%) HBNE workers used tightly fit canalphones that provided passive noise isolation. Of the remaining 25% of HBNE workers, 1 of 12 (8.3%) used earbuds and 2 of 12 (16.7%) used supra-aural headsets, which provided no substantial noise attenuation. Of the LBNE category, 10 of 12 (83.3%) subjects used supra-aural headsets without substantial noise attenuation, and 2 of 12 (16.7%) used tightly fit canalphones that provided passive noise isolation. Among all 24 subjects, only one LBNE worker (4.2% of total subjects) chose to use an output limiting device or software to restrict the maximum output level of their PMP. A summary of subject PMP and headset information is provided in Table 5.3.

Table 5.3: Subject PMP and Headset Information by Noise Exposure Category

<table>
<tr><th>Exposure Category</th><th>Proportion of Subjects by PMP Device</th><th colspan="2">Proportion of Subjects by Headset Type</th><th>Proportion of Subjects by Noise Attenuation Type</th><th>Proportion Using Output Limiting Technology</th></tr>
<tr><td rowspan="3">High-Background Noise (n=12)</td><td>MP3 Player
66.7%
(n=8)</td><td>Supra-aural
16.7%
(n=2)</td><td>Earbud
8.3%
(n=1)</td><td>Active
25%
(n=3)</td><td rowspan="3">0 %
(n=0)</td></tr>
<tr><td rowspan="2">Cellular Phone
33.3%
(n=4)</td><td rowspan="2">Circumaural
25%
n=3</td><td rowspan="2">Canalphon
e
50%
n=6</td><td>Passive
50%
(n=6)</td></tr>
<tr><td>None
25%
(n=3)</td></tr>
<tr><td rowspan="2">Low-Background Noise (n=12)</td><td rowspan="2">Computer
100%
(n=12)</td><td colspan="2">Supra-aural
83.3%
(n=10)</td><td>Passive
16.7%
(n=2)</td><td rowspan="2">8.3 %
(n=1)</td></tr>
<tr><td colspan="2">Canalphone
16.7%
(n=2)</td><td>None
83.3%
(n=10)</td></tr>
</table>

<u>Background Noise Levels:</u>

A two-minute background L_{Aeq} (the A-weighted SPL that would produce the same exposure over the measurement period as the time-varying SPL, calculated using a three dB exchange rate) was measured with a SLM at each subject's work area. The mean background L_{Aeq}, with 95% confidence interval, measured in LBNE areas was 58.6 dBA (57.0, 60.2). The mean background L_{Aeq}, with 95% confidence interval, measured by SLM in HBNE areas was 81.2 dBA (78.2, 84.2). The difference between the mean background L_{Aeq} for HBNE and LBNE workers was 22.6 dBA. A second set of background noise measurements was taken for HBNE workers using personal noise dosimeters, which resulted in a mean background L_{Aeq}, with 95% confidence interval, of 80.3 dBA (76.7, 84.0).

A comparison between background L_{Aeq} levels measured by SLM and dosimeters was conducted to determine how closely a two-minute SLM measurement compared to work-shift dosimetry sampling. Because dosimeter and SLM L_{Aeq} measurements were each performed on the same subjects during the same work-shift, a Paired T-Test was conducted to compare the mean difference of the pair-wise L_{Aeq} measurements. There was no significant difference between the mean background SLM measurements and the mean dosimeter measurements (p-value=0.6608). A summary of background and work-shift noise levels is included in Table 5.4. A comparison of SLM and dosimeter measurements is given in Figure 5.1.

Table 5.4: Mean Background and Work-shift L_{Aeq}, by Instrument Type and Noise Exposure Category

Instrument	**High-Background Noise (n=12)**	**Low-Background Noise (n=12)**
SLM	81.2 dBA (78.2, 84.2)	58.6 dBA (57.0, 60.2)
Dosimeters	80.3 dBA (76.7, 84.0)	

p-value=0.6608

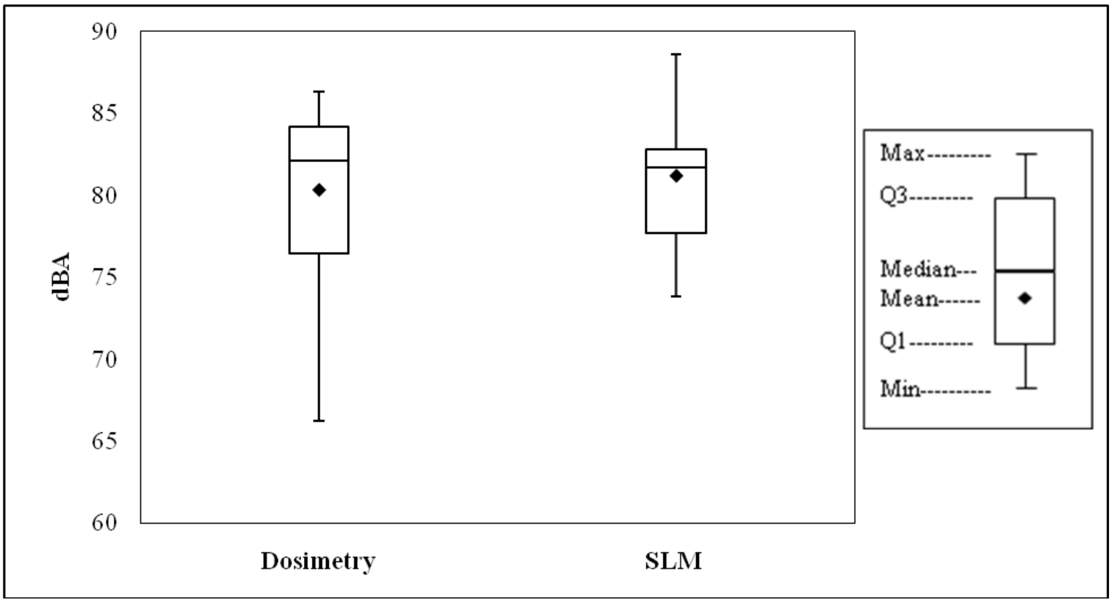

Figure 5.1: Comparison of Background L_{Aeq} and Work-shift L_{Aeq} Levels Measured for HBNE Subjects

PMP Listening Levels:

A two-minute PMP listening level sample for each subject was measured with an ear simulator in each subject's work area. Ear simulator measurements were then converted to listening level FFL_{Aeq} (the free-field equivalent, A-weighted SPL that would produce the same exposure over the measurement period as the time-varying SPL, calculated using a 3 dB exchange rate). The mean FFL_{Aeq} listening level, with 95 percent confidence interval, measured for LBNE subjects was 75.0 dBA (70.9, 79.0). The mean FFL_{Aeq} listening level, with 95 percent confidence interval, measured for HBNE subjects was 84.7 dBA (80.6, 88.8). The difference between the mean FFL_{Aeq} listening levels for HBNE and LBNE subjects was 9.7 dBA.

A One-Sided, Two-Sample T-Test was performed to determine if the mean FFL_{Aeq} listening levels of HBNE subjects was significantly higher than the FFL_{Aeq} listening levels of LBNE subjects. The mean FFL_{Aeq} listening level for HBNE subjects was significantly greater than the mean FFL_{Aeq} listening level for LBNE subjects (p-value=0.0006). The assumptions of normality and homogeneity of variance were met for FFL_{Aeq} listening levels for HBNE and LBNE subjects. A summary of HBNE and LBNE listening levels is provided in Table 5.5. A comparison of HBNE and LBNE listening levels is given in Figure 5.2.

Table 5.5: FFL_{Aeq} Listening Levels, by Noise Exposure Category

Exposure Category	**Mean FFL_{Aeq} Listening Level**
High-Background Noise (n=12)	84.7 dBA (80.6, 88.8)
Low-Background Noise (n=12)	75.0 dBA (70.9, 79.0)

p-value=0.0006

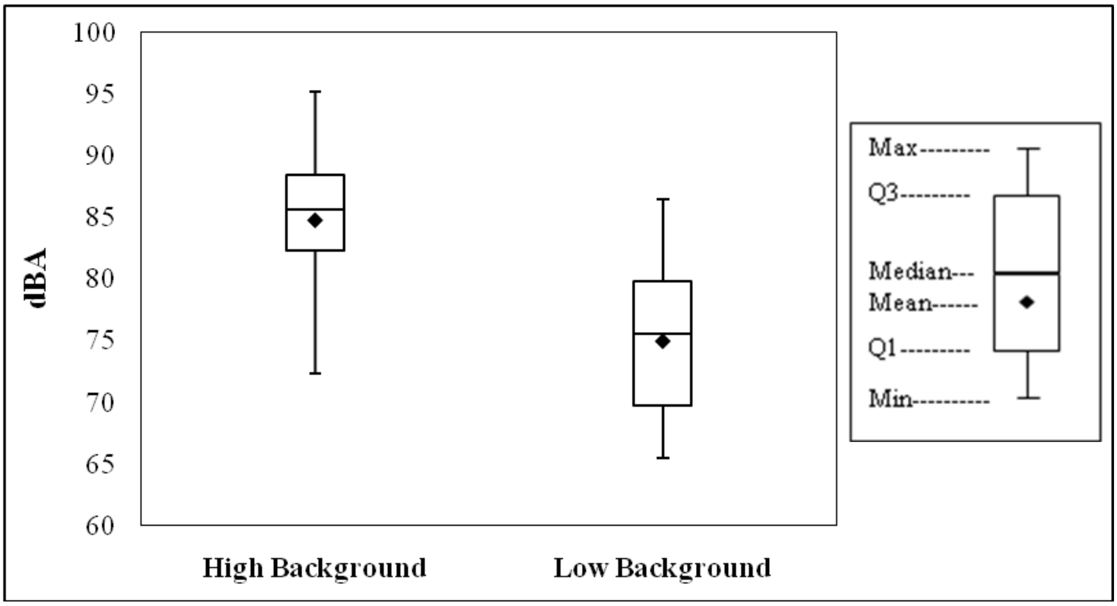

Figure 5.2: Comparison of FFL_{Aeq} Listening Levels Measured for HBNE and LBNE Subjects

Headset Attenuation Estimates:

An estimate of headset attenuation for HBNE workers was performed by subtracting the FFL_{Aeq} measured with the ear simulator coupled with the subjects' earpieces, from the FFL_{Aeq} measured with the open ear simulator in the subjects' work areas. The mean attenuation estimate for all headset device types was 5.2 dB (1.3, 9.4). The mean attenuation estimates, with 95 percent confidence intervals, for noise exposure categories and individual headset device types were also calculated. A summary of attenuation estimates is provided in Table 5.6.

Table 5.6: Attenuation Estimates with 95% Confidence Intervals, by Noise Exposure Category and Headset Device Type

Group	Number	Attenuation FFL_{Aeq} Levels
All Headsets	24	5.2 dB (1.3, 9.14)
High Background	12	10.3 dB (3.6, 17.0)
Low Background	12	0.1 dB (-2.0, 2.3)
Circumaural	3	20.0 dB (-10.0, 50.1)
Canalphone	8	8.2 dB (1.5, 15.0)
Earbud	1	-1.8 dB (N/A)
Supra-aural	12	0.1 dB (-2.1, 2.4)

Signal-to-Noise Ratios:

The signal-to-noise ratio (the difference between FFL_{Aeq} and L_{Aeq}, which indicates the degree to which PMP users increase the headset output signal to mask unwanted background noise interference) was calculated for each subject by subtracting the measured FFL_{Aeq} from the SLM measured L_{Aeq}. The combined mean signal-to-noise ratio, with 95 percent confidence interval, for both background exposure categories was 9.9 dBA (6.2, 13.7). The mean signal-to-noise ratio, with 95 percent confidence interval, for HBNE and LBNE subjects was 3.5 dBA (-0.1, 7.1) and 16.3 (12.2, 20.5) respectively. There were too few of each category of headset noise attenuation and headset type (see Table 5.3) to perform a statistical comparison of subjects' signal-to-noise ratio by noise attenuation or headset device type alone. Thus, the categories were combined into two categories. The 'noise attenuation' category included all circumaural headsets and canalphones classified as active noise cancelling or passive noise isolating (n=11). While the 'no noise attenuation' category included all earbuds and supra-aural headsets classified as providing no noise attenuation (n=13). The mean signal-to-noise ratio, with 95 percent confidence interval, for the noise attenuation category was 4.6 dBA (-0.4, 9.7). The mean signal-to-noise ratio with 95 percent confidence interval for the no noise attenuation category was 14.4 dBA (9.9, 18.9).

Paired T-Tests were conducted to compare the mean signal-to-noise ratios by background exposure and noise attenuation categories. The results indicated a significant difference between the signal-to-noise ratios of HBNE and LBNE subjects (p-value=0.00004). There was also a significant difference in mean signal-to-noise ratios between subjects that used headsets with noise attenuating features as opposed to those that used headsets without noise attenuating features (p-value=0.0043). The assumptions of the Paired T-Test were met for the data. A summary of signal-to-noise ratios by background noise and noise attenuation exposure categories is provided in Table 5.7. Comparisons of signal-to-noise ratios by background exposure category and by noise attenuation category are given in Figures 5.3 and 5.4.

Table 5.7: Signal-to-Noise Ratios of Subjects, Overall and by Noise Exposure Category and Headset Noise Attenuation Category

Grouping	Number of Subjects	Signal-to-Noise Ratio
Overall	24	9.9 dBA (6.2, 13.7)
High-Background	12	3.5 dBA (-0.1, 7.1)
Low Background	12	16.3 dBA (12.2, 20.5)
Noise Attenuating	11	4.6 dBA (-0.4, 9.7)
Non-Noise Attenuating	13	14.4 dBA (9.9, 18.9)

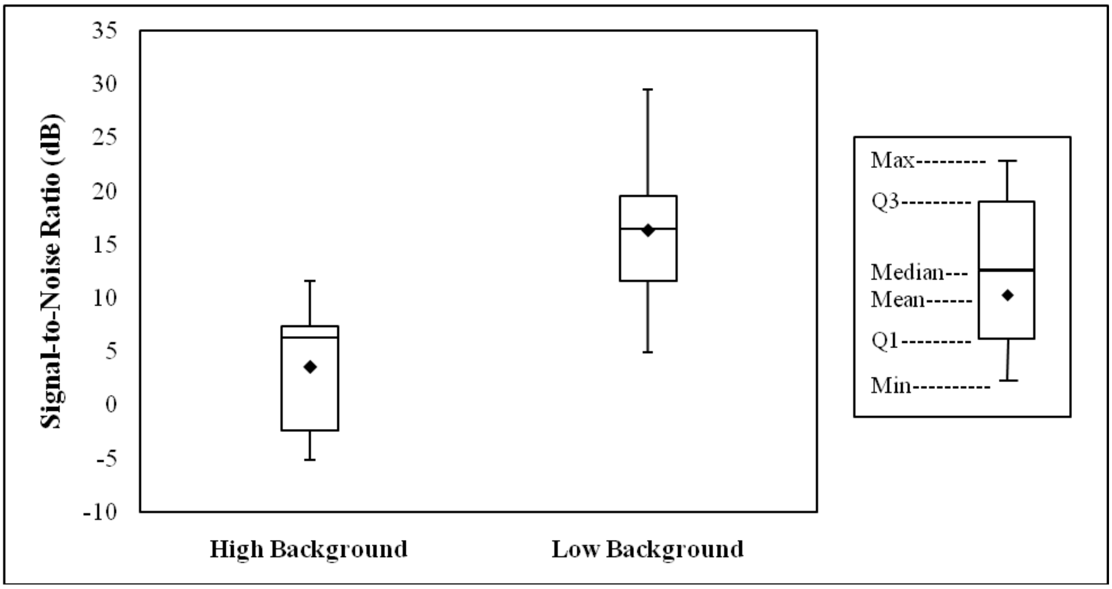

Figure 5.3: Comparison of the Signal-to-Noise Ratios of HBNE and LBNE Subjects

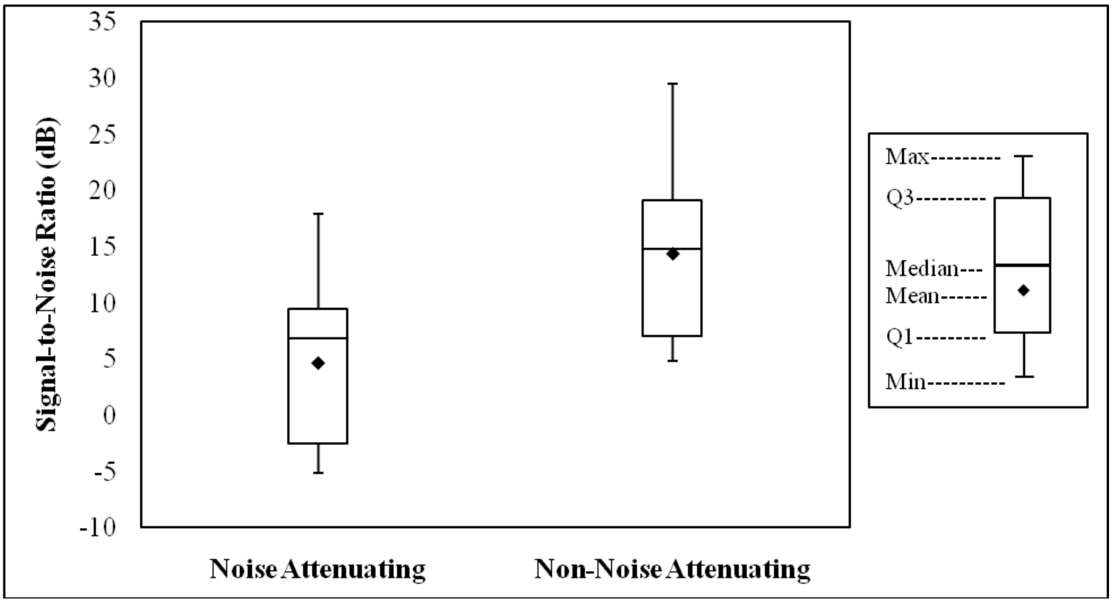

Figure 5.4: Comparison of the Signal-to-Noise Ratios of Subjects Who Chose Noise Attenuating Headsets vs. Subjects Who Did Not

Daily Occupational Noise Exposure Estimates:

Occupational noise exposure estimates incorporating periods of listening (FFL_{Aeq}) and background noise (L_{Aeq}) were calculated for the work-shifts of HBNE and LBNE subjects. The mean percent noise dose calculated using NIOSH and ACIGH criteria (85 dBA eight-hour TWA exposure limit, calculated using a 3 dB exchange rate) for HBNE subjects was 146.6 percent. The mean percent noise dose using ACIGH criteria for LBNE subjects was 13.7 percent. The mean nominal eight-hour TWA, with 95 percent confidence interval, for HBNE and LBNE workers was 84.3 (81.2, 87.5) and 71.5 dBA (67.1, 75.9) respectively. Six of 12 (50%) HBNE subjects were overexposed to noise according to ACGIH criteria. No LBNE subjects exceeded the ACGIH criterion.

A One-Sided, One-Sample T-Test was conducted to determine if the mean eight-hour TWA for HBNE workers was greater than the ACGIH criterion of 85 dBA eight-hour TWA. There was not sufficient evidence to demonstrate a mean overexposure (p-value=0.6762). The assumption of normality was met for occupational noise exposure estimates. A comparison between HBNE and LBNE estimates is given in Figure 5.5. A comparative graph that depicts the mean ACGIH eight-hour TWA as well as mean background L_{Aeq} level and FFL_{Aeq} listening level by noise exposure category is provided in Figure 5.6. Occupational noise exposure estimate results are presented in Table 5.8.

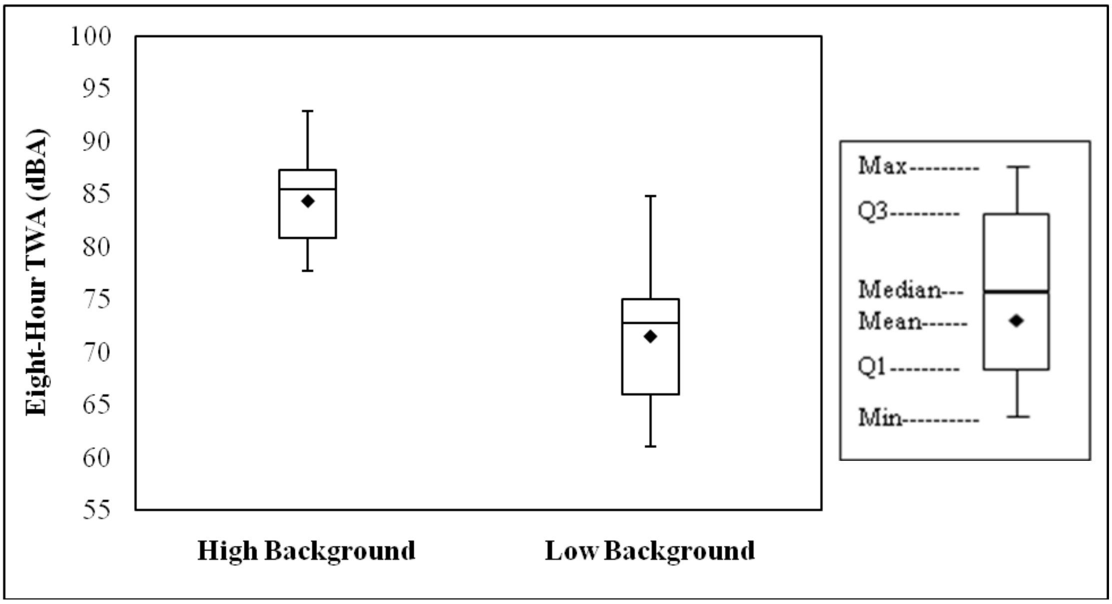

Figure 5.5: Comparison of the ACGIH Eight-Hour TWA of HBNE and LBNE Subjects

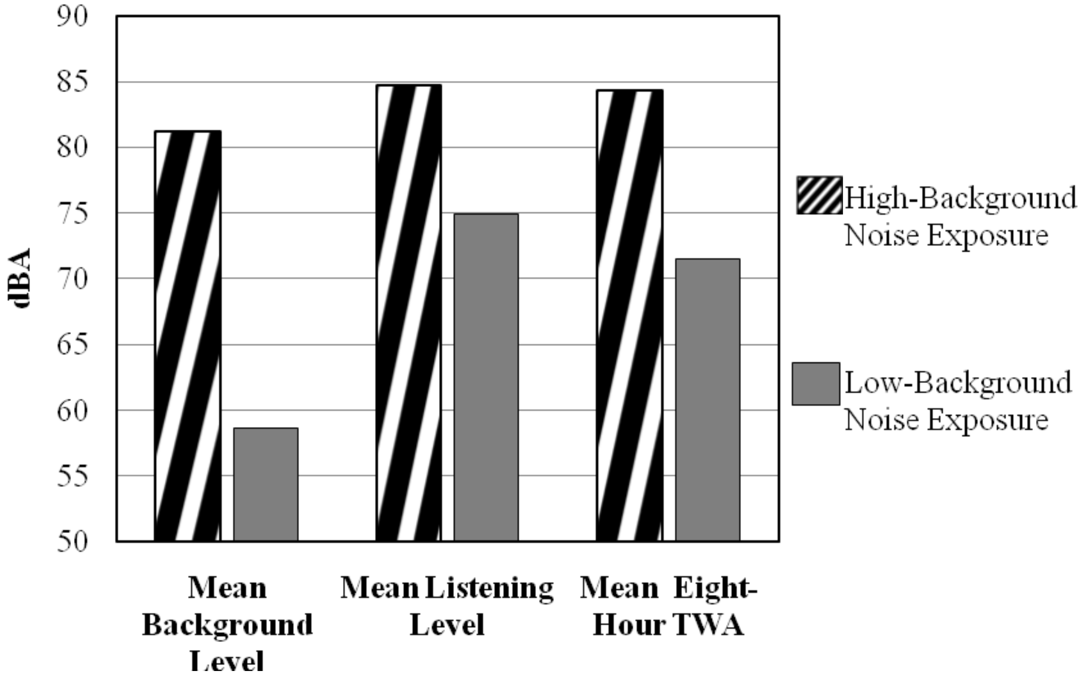

Figure 5.6: Mean Background L_{Aeq} Levels, FFL_{Aeq} Levels, and Eight-Hour TWAs as Calculated Using ACGIH Criteria for HBNE and LBNE Subjects

Table 5.8: Mean ACGIH Occupational Exposure Estimates by Background Noise Category

Exposure Category	**ACGIH Criteria**		
	Mean Eight-Hour TWA[a]	Range of TWAs	Number of Subjects > 85 dBA
High-Background Noise (n=12)	84.3 dBA	77.8 - 92.9 dBA	6
Low-Background Noise (n=12)	71.5 dBA	61.0 - 84.8 dBA	0

a - Calculated using Equation 4.2

Discussion:

The mean occupational exposure estimates for HBNE and LBNE categories were not statistically greater than NIOSH and ACGIH occupational exposure limits. However, 6 of 12 (50%) of all HBNE subjects had exposure estimates greater than 85 dBA eight-hour TWA when both PMP listening levels and background noise were taken into account. No occupational noise exposure estimates indicated an overexposure among LBNE subjects. Additional exposure estimates without the inclusion of PMP listening levels (i.e., using background noise levels only) indicated that only 3 of 12 (25%) of subjects would be exposed to noise greater than 85 dBA eight-hour TWA. Thus, in this study, the policy allowing workplace PMP use appears to have doubled the number of HBNE subjects overexposed to noise. Additionally, the number of overexposed subjects would increase further if worker PMP listening times were extended to eight hours or more as opposed to the self-reported listening time mean of 3.6 hours per day for both HBNE and LBNE subjects. Exposure estimates based upon only background L_{Aeq} levels are provided in Table 5.9.

Table 5.9: Mean ACGIH Occupational Exposure Estimates by Background Noise Category, Calculated Using only Background L_{Aeq} Levels and Work-shift Length, while Omitting FFL_{Aeq} Listening Levels and Listening Times

Exposure Category	**ACGIH Criteria**		
	Mean Eight-Hour TWA[a]	Range of TWAs	Number of Subjects > 85 dBA
High-Background Noise L_{Aeq} (n=12)	82.4 dBA	75.1 - 89.8 dBA	3
Low-Background Noise L_{Aeq} (n=12)	58.9 dBA	54.8 - 62.3 dBA	0

a - Calculated using Equation 4.2

Although the total mean signal-to-noise ratio was approximately 10 dBA, which is reasonable for masking background noise, it was surprising that the mean signal-to-noise ratio for HBNE workers (3.5 dBA) was so much lower than the signal-to-noise ratio for LBNE workers (16.3 dBA). However, when headset device selection and noise attenuation technology were considered, the discrepancy between HBNE and LBNE subjects appears to be more reasonable. Because HBNE subjects were working in relatively loud environments, they likely had greater motivation to select headsets that would allow them to listen to media with reduced interference from background noise. However, 92 percent of LBNE workers indicated they used PMPs to drown out noise, yet only 17 percent used headsets with noise attenuating features. Comparatively, only 50 percent of HBNE workers indicated they used PMPs to drown out noise although 75 percent used headsets with noise attenuating features. The discrepancy between reported PMP use for background noise masking purposes and headset selection suggests that the facility workforce may not be educated regarding options to limit background noise interference during PMP use. Measurement and calculation of headset attenuation estimates provided little useful information because of the limited numbers of each headset type observed and the large variance in attenuation levels.

The application of discrete two-minute SLM measurements proved to be a reliable work-shift approximation for use in signal-to-noise ratio and occupational exposure estimates. Given that there was only a difference of 1 dBA between the mean background and work-shift L_{Aeq} levels, and the accuracy of the measurement devices, it was not surprising that the background L_{Aeq} levels measured with the SLM were not significantly different from work-shift dosimeter L_{Aeq} measurements. The similarity between SLM and dosimeter measurement results is likely because noise sources in the facility were relatively constant and worker mobility was minimal in both production and office areas.

HBNE subjects were measured during both day and night shifts to account for any potential differences in exposures between shifts. A Two-Sided, Two-Sample T-Test was conducted to compare the background L_{Aeq} levels and FFL_{Aeq} listening levels for HBNE subjects by shift category (day and night). The results were not significantly different for L_{Aeq} levels (p-value=0.4545) or for FFL_{Aeq} listening levels (p-value=0.7339), thus only the combined HBNE category results were presented. In addition, background and listening level measurements were not significantly different between Office A and B, and Plant A and B. There were not enough females in the HBNE category to make a comparison by gender; therefore, gender was not used as a classification variable.

Production areas in the facility operate using a rotating worker system. In theory, each worker may operate any job task on any particular day. In practice, this was not entirely true, as a minority of workers tended to be entrenched in certain jobs and did not rotate to other tasks. For worker protection purposes, a blanket approach (i.e., protection against the highest noise exposure for all workers) is the most conservative. Using the blanket approach, the exposure level requiring protection would be the highest individual background L_{Aeq} based eight-hour TWA (as an estimate for work-shift L_{Aeq}) of 90 dBA, and the highest combined eight-hour TWA (which incorporates listening times) of 93 dBA, using ACGIH Criteria. Individual subject measurement results are provided in Appendix B.

Limitations:

The primary limitation of this study is the inability to draw inferences about the general working population. The target population could essentially be limited to the total workforce at the production facility in which subjects were sampled (i.e., those workers at the facility who were not solicited for participation or who did not choose to participate). Less conservatively, the results could be applicable to similar industries with similar PMP use policies and similar noise exposures. In any case, the results certainly cannot be applied across multiple occupational sectors and types. Further, only rough estimates regarding the prevalence of PMP use at the sample facility were available. Before drawing any broadly applicable conclusions, an estimate of the prevalence of occupational PMP use should be available.

There were several limitations regarding the measurement techniques and equipment used in this study. The SLM and dosimeters used in this study were 'type two' instruments, meaning they are accurate to within ± 2 dB. This ± 2 dB accuracy range accounts for instrument and measurement variability. Ear Simulator method variability was also estimated to be approximately ± 2 dBA, which includes not only instrument and measurement variability, but also deviations of the ear simulator ear and the associated headset fit from the actual ears of subjects (ISO, 2004). Given the limitations of the measurement accuracy ranges, exposure estimates were re-calculated with an increase of 2 dBA in measured FFL_{Aeq} and L_{Aeq} levels. Only the 2 dBA increase was considered because it provides the more conservative results in terms of estimating worker dose. The results remained largely unchanged following the 2 dBA increase. One additional subject in HBNE and LBNE categories would have been overexposed according to NIOSH and ACGIH criteria. The One-Sided, One-Sample T-Test comparing mean daily exposure estimate with the ACGIH criterion (85 dBA eight-hour TWA) was repeated using data that had been increased by 2 dBA. The result was still not significant (p-value=0.1626). A summary of noise exposure estimates following a 2 dBA increase of measured FFL_{Aeq} and L_{Aeq} levels is provided in Table 5.10. Following a 2 dBA increase, use of the blanket approach to employee protection would require protecting all HBNE workers against background TWA exposures of 92 dBA and background and listening combined exposures of 95 dBA.

Table 5.10: Mean ACGIH Occupational Exposure Estimates by Background Noise Category, Calculated Following a 2 dBA Increase in FFL_{Aeq} and L_{Aeq}.

Exposure Category	**ACGIH Criteria**		
	Mean Eight-Hour TWA[a]	Range of TWAs	Number of Subjects > 85 dBA
High-Background Noise L_{Aeq}	86.3 dBA	79.8 - 94.9 dBA	7
Low-Background Noise L_{Aeq}	73.5 dBA	63.0 - 86.8 dBA	1

a - Calculated using Equation 4.2

Another limitation of this study was the not calculating OSHA exposure estimates based upon the FFL_{Aeq} and L_{Aeq} measurements. The FFL_{Aeq} and L_{Aeq} levels were measured using an 80 dBA threshold level and a 3 dBA exchange rate, per NIOSH and ACGIH recommendations. However, compliance with OSHA standards requires measurement with a 5 dBA exchange rate and a 90 dBA threshold for comparison to the PEL. Although calculations for allowable exposure time could incorporate OSHA criteria, the measurements themselves could not because the ISO 11904-2:2004 standard specifies using L_{eq} measurements that are measured with a 3 dB exchange rate. Because FFL_{Aeq} and L_{Aeq} levels were treated as discrete interval exposures during listening and non-listening times, any calculated OSHA percent noise dose and eight-hour TWA would likely be exaggerated.

There were also limitations regarding the measurement techniques used in this study. The ISO 11904-2 standard specifies a true signal-to-noise ratio of 10 dB for each un-weighted 1/3 octave band for signals measured with the ear simulator (ISO, 2004). The true signal-to-noise ratio described in ISO 11904-2 should not be confused with the signal-to-noise ratios calculated between L_{Aeq} and FFL_{Aeq}. However, because the experiment was conducted in-situ (i.e., in subjects' noise environment with subjects choosing their own players, headsets, and listening levels) the true signal-to-noise ratio could not be ensured without increasing the PMP listening level. Of course, an intentional increase of PMP listening levels would negate the study results. The signal-to-noise ratio requirement was therefore not met for many subjects, particularly in HBNE areas. The measurement and calculation of headset attenuation estimates was also not consistent with the ISO standard. For external noise sources not coupled to the ear, the ISO 11904-2 is only accurate if the full head and torso simulator (HATS) mannequin is utilized (ISO, 2004). Because an ear simulator was used, only the measurements from sources coupled directly to the ear, such as PMP headsets, were accurate to within the method limitations (± 2 dBA). Since attenuation estimates were calculated by measuring external noise using an ear simulator with and without a coupled earpiece, the estimates have unknown accuracy and may not be reliable.

The use of two-minute SLM measurements in the calculation of occupational exposure estimates was verified via comparison with work-shift dosimetry sampling, because background noise exposures were relatively constant for individual workers.

However, the researchers were not able to verify the FFL_{Aeq} measurements with a similar method. Consequently, the listening time exposure used in the calculation of occupational noise exposure estimates is essentially a 2-minute grab sample, which may not accurately depict the true time-variable exposures.

The method in which subjects were identified and sampled is another source of potential limitations. The production facility was not chosen because it was representative of any particular industry or demographic, but rather as a convenience sample. Subjects were asked in person whether they used PMPs at work, and although management corroborated the responses, some still may have chosen not to disclose their occupational PMP use. The researchers also moved throughout the selected work areas to solicit volunteers and conduct measurements. Thus, workers were likely aware of the researchers' approach and may have had the opportunity to adjust the listening level of their PMPs prior to the researchers' arrival at their workstation. Non-differential worker adjustment of listening level would likely only bias results toward the null. However, HBNE workers may have been more likely to adjust their listening level because they may have been afraid of losing their listening privileges in high-background noise work areas. This potential non-differential listening level adjustment could bias the high- and low-background noise comparisons towards the null. The researchers' presence may also have unduly influenced the level of background noise exposures, as workers or their supervisors may have been more careful to limit loud noise sources or risky behaviors while the researchers were present.

Facility noise exposures in high-background noise exposure areas did not appear to be homogenous, but rather consisted of many individuals and small groups performing discrete tasks. Therefore, a random sample of workers would likely have failed to capture exposures from entire work tasks. Instead, exposures were sampled using what could be considered a partial census method. Specifically, every worker was solicited who was working in Plants A and B and Offices A and B during the sampling visits. Although night and day shift workers were accounted for, the sampling strategy failed to capture workers who were on a day off or who were working in other areas of the facility. Because PMP and headset device types were not controlled, the sample population also did not include sufficient numbers of each type for statistical comparison beyond pooled noise attenuation categories. A larger sample size could provide enough power to make comparisons by other classification variables, such as gender, ethnicity, and headset type.

CHAPTER 6: CONCLUSIONS AND RECOMENDATIONS

The evaluation of worker background L_{Aeq} levels, FFL_{Aeq} listening levels, and PMP listening behaviors was conducted in this pilot study to test the following research hypothesis and address the following three specific aims:

Research Hypothesis:

Noise from PMPs contributes to worker overexposure to noise as compared to published exposure limits.

The results failed to reject the null hypothesis that the mean occupational exposure for HBNE and LBNE subjects listening to PMPs in high- and low-background noise environments was less than or equal to 85 dBA eight-hour TWA based upon NIOSH and ACGIH noise exposure criteria.

Specific Aims:

1. *Measure and evaluate the chosen sound-output levels from the use of PMPs in the workplace.*

The ear simulator measurement techniques used in this study were developed in accordance with ISO 11904-2. The results have a potential error of ± 2 dBA.

However, the requirement for a 10 dB true signal-to-noise ratio for each un-weighted 1/3 octave band was not met. The requirement was violated because PMP listening levels were measured at subjects' workstations, in subjects' background noise environment, without altering subjects' PMP volume or headset type. Failure to ensure the 10 dB true signal-to-noise ratio could further affect the accuracy and precision of the ear simulator measurements. Because only an ear simulator and not a HATS mannequin was used to measure PMP listening levels, any background noise that leaked through the headset during measurements would not have been consistent with the levels that would have occurred via the normal reflections off the planes of the human body. Overall, the measurement techniques used in this study should provide reasonable PMP listening level estimates.

2. *Determine if workers are overexposed to noise from using PMPs.*

Some workers were overexposed to noise from using PMPs at work as opposed to background noise alone. The results indicated that 50% of HBNE subjects were overexposed to noise (according to ACGIH criteria) when PMP use was considered, as opposed to only 25% when only background noise was considered; a 100% increase in overexposures from workplace PMP use. The results also indicated that no LBNE workers were overexposed to noise from using PMPs.

3. *Evaluate the relationship between sound-output levels of PMPs to background workplace noise.*

The mean FFL_{Aeq} listening level for HBNE workers (84.7 dBA) was significantly higher than the mean FFL_{Aeq} for LBNE workers (75.0 dBA). The mean signal-noise-ratio between FFL_{Aeq} listening levels and background L_{Aeq} noise levels was approximately 10 dBA for both HBNE and LBNE subjects. However, the mean signal-noise-ratio for HBNE subjects was only 3.5 dBA as compared to 16.4 dBA for LBNE subjects. The type of headset device that subjects used affected the signal-to-noise ratio. The mean signal-to-noise ratio for subjects who used noise attenuating headsets was much lower (4.6 dBA) than subjects who used headsets with no noise attenuation (14.4 dBA). HBNE subjects were much more likely to use noise attenuating headsets as compared to LBNE subjects. Although higher background noise levels seem to be an indicator of higher listening levels, headset device type and noise attenuating technology also appear to influence the relationship between background noise and listening level.

<u>Conclusion:</u>

The results of this study indicated overexposures to noise among workers who used PMPs in high-background noise exposure areas, although the mean exposure was not above ACGIH criteria. Exposure estimates indicated that there was a 100 percent increase in overexposed subjects when PMP use was considered as opposed to background noise exposures alone. PMP listening level measurements indicated that 8 of 24 (33.3%) subjects (including one in low-background noise exposure areas) listened at levels greater than 85 dBA FFL_{Aeq}, although self-reported listening times did not often meet or exceed eight hours. Further, the results indicated that PMP listening levels were at least in part dictated by background noise level. However, background noise level alone cannot predict listening level, which also appears to be dependent upon PMP headset device type and noise attenuation capability.

Pilot Study Recommendations:

This pilot study provided a reasonable method for evaluating worker PMP listening levels and calculating the resultant occupational noise exposures. Some modifications to this method should be made for future projects evaluating the occupational exposures of workers who use PMPs while on the job. The inability to ensure a 10 dB true signal-to-noise ratio indicates that some background noise leakage may have occurred during the in-situ listening level measurements. This effect would largely be determinant on the worker's chosen listening level, the background noise level, and the attenuation of the worker's headset. Because the goal was to determine the actual noise exposures, background noise leakage was not in and of itself a problem. However, a full HATS mannequin should be used for future studies of this type to ensure that the background noise is reflected appropriately off the planes of the body and not distorted by reflecting off surfaces used to support the ear simulator. In addition, FFL_{Aeq} levels determined via the ISO 11904-2 standard should not be directly compared to OSHA noise exposure regulations without appropriate time averaging adjustments and threshold considerations. Comparison with NIOSH and ACGIH recommendations based upon current ONIHL damage risk criteria are appropriate when using the ISO 11904-2 standard.

The site selected for evaluation during this pilot study was selected primarily for convenience. For inferential purposes, future studies of this type should attempt to identify multiple workplaces representative of large occupational sectors that permit the use of PMPs. As was done in this study, an effort to verify brief background SLM measurements with another exposure evaluation method should be considered. Exposure estimates made using brief listening level measurements should also be verified via multiple sampling times throughout the work-shift or through other means. An effort to evaluate not only the prevalence of PMP use at workplaces, but also the PMP headset device and attenuation types should also be made to ensure an adequate sample size for analysis by these classification variables. Workplaces that have personnel groups performing large homogenous work tasks should be randomly sampled by work task category.

Worker Protection Recommendations:

The results of this pilot study indicated overexposure to noise among workers who used PMPs in high-background noise exposure areas. Because of the rotating work schedule at the facility, the blanket worker protection approach indicates that all workers on the production floor of both plants should be enrolled in a hearing conservation program. The employer should consider feasible administrative and engineering controls to reduce hazardous noise exposures on the production floor and provide appropriate HPDs for employees as required by OSHA regulations. Although some PMP headsets appear to provide good noise attenuation, they are not manufactured and tested as HPDs according to industry standards, such as the American National Standards Institute (ANSI) standard S12.6 (ANSI/ASA, 2008). To reduce the risk of compensable ONIHL and regulatory violations, the employer should both implement and enforce a policy that discourages PMP use while promoting traditional HPD use. As an alternative, the employer should consider providing specially manufactured, combined HPD/PMP headsets to employees that incorporate output limiting technology and are properly tested for HPD noise attenuation, which would allow workers to enjoy media listening during work without increasing their risk of hearing impairment. Before selecting any combined HPD/PMP headsets for workers, the employer should confirm that sufficient noise attenuation would be provided and ascertain any additional safety or health hazards that would be created by their use. The audiograms for workers in a hearing conservation program who continue to use PMPs at work should be monitored for any deviations in hearing thresholds from the rest of the workforce.

There was no evidence of overexposures to noise among LBNE workers regardless of PMP use. However, PMPs and headsets used by LBNE subjects do have the potential to create an overexposure if used for long periods and high volumes throughout the day. The employer should therefore consider requiring headsets or PMPs with output limiting technology to LBNE workers, which would ensure no workplace PMP listening level overexposures would occur. All employees permitted to use PMPs at work should be formally educated on the risks of loud media listening and on the available options to limit exposures.

Future Research Recommendations:

The results of this study indicated that overexposures to noise could occur in workers who are permitted to use PMPs while working in high-background noise environments. However, more information is needed to determine at what background noise level employers should cease allowing workers to use PMPs and headsets indiscriminately. Further, there is evidence that suggests a small but substantial proportion of PMP users will listen at levels greater than 85 dBA TWA regardless of background noise exposures. Acceptable hearing impairment risk from occupational PMP use must also be considered. Thus, providing information that can aid in the determination of a ‘safe’ background noise level for workplace PMP use, if any, should be a top priority. Dosimetry techniques for directly measuring daily noise exposures from PMP listening should also be considered.

The additional safety and health implications of occupational PMP listening is another topic which should be explored by researchers. If PMP use inhibits critical communication or distracts workers from potentially hazardous tasks, there may be greater concerns about PMP use beyond hearing impairment risk. Electromagnetic fields and other potential non-auditory hazards and health risks should also be considered, as well as potential control methods such as intrinsically safe technologies.

Anecdotal evidence suggests that there are a number of workers in many occupational sectors who use PMPs while working. However, an estimate of the prevalence and magnitude of workplace PMP use for the general working population or by occupational sector should be a main objective of future research. An epidemiologic study designed to measure noise exposure levels and hearing acuity over time should be conducted to determine if the risks for occupational PMP listening are comparable to the risks of industrial noise exposures. Ultimately, studies designed to provide reasonable inference to the greater working population are necessary for estimating the burden to society posed by potential hearing impairment and other health effects caused by the occupational use of PMPs.

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APPENDIX A

Worker Questionnaire and Data Sheet

Worker Questionnaire and Data Sheet

Investigator Name: ____________________________ Date/Time: ________________ Subject ID#_______

Task that employee was performing during measurement: ____

Two-minute background noise measurement at location during work: ___________dBA. SLM Test #_______

1. What is your age? ________ years
2. What is your gender? M F
3. What is the name of your work division, department, or section? ________________________
4. What is your job title? ____
5. On average, how many hours per day do you work, excluding lunch? ___________ hr/day
6. On average, how many days per week do you work? ___________ days/week
7. On average, how many hours/day do you listen to your PS during work? _______hr/day
8. On average, how many hours/day do you listen to your PS before and after work? ______hr/day
9. On average, how many hours/day do you listen to your PS on your days off? _________ hr/day
10. How long have you used a PS? 1-6 months 6-12 months 1-2 years 2-5 years > 5 years
11. Yes or no, do you use your PS to drown out other noises in the workplace? Y N
12. Yes or no, do you use your PS to drown out other noises at home? Y N
13. Yes or no, do you use an output limiter? *(explain output limiter if needed)* Y N

Open ear file #__________ Pink noise file # ________________ No noise w/ earphone file #__________

Two-minute "at-ear" SPL measured with artificial ear: _______________dBA. SLM File #_____________

Approximate % of volume setting during PS measurement (circle one):

10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100

Type of music measured (circle one):

Alternative Rock	Comedy/Spoken	Gospel	Pop
Blues	Country	Hard Rock/Metal	Rap & Hip Hop
Christian Music	Dance & Electronic	Jazz	R&B
Classic Rock	Easy Listening	Latin Music	World Music
Classical	Folk	New Age	Other: ______________

Title of song(s) measured from test subject if known:

1. ____ 2. ______________________________________

Type of PS measured: MP3 Compact Disc Player Computer Radio Cellular Phone

Brand/Model of PS if known: ____

Brand/Model of earphone if known: ____

Active or passive noise canceling headphone: Active Passive None Unknown

Type of earphone: Canalphone Earbud Supra-aural *(sits on top of the ear)* Circumaural *(surrounds the ear)*

APPENDIX B

Individual Subject Data

Table B.1: (Supplemental) Individual Questionnaire Results for High Background-Noise-Exposed Subjects

High Background Noise Exposed Subjects											
Subject	Age (years)	Gender	Work-Shift (hrs/day)	Work Days/Week	Daily Workplace PMP Listening Time (hrs)	Daily PMP Listening Time Before & After Work (hrs)	Daily PMP Listening Time, Days Off (hrs)	Duration of PMP Use (yrs)	PMP Used to Mask Workplace Noise?	PMP Used to Mask non-Workplace Noise?	Output Limiter Technology Used?
1	38	M	10	4	4	1	2	>5	yes	no	no
2	42	F	10.5	4	9	0	0	0.5 to 1	yes	no	no
3	33	M	11	4	5	0	3	2 to 5	no	yes	no
4	38	M	10	4	3	0	0	2 to 5	yes	no	no
5	30	M	11	4	0.75	1	1	2 to 5	no	no	no
6	36	M	10	4	1	1	1	>5	no	no	no
7	38	M	11	3.5	5	0	0	0.5 to 1	no	no	no
8	25	M	10	3.5	5	0	0	1 to 2	yes	no	no
9	29	M	10.5	4	3	0	0	>5	no	no	no
10	38	M	11	4	3	2	3	>5	yes	no	no
11	34	M	10	4	2	0	0.5	>5	yes	no	no
12	32	M	11	4	6	2	1.5	>5	no	no	no
Averages	34.4		10.5	3.92	3.9	0.58	1				

Table B.2: (Supplemental) Individual Questionnaire Results for Low Background-Noise-Exposed Subjects

Low Background Noise Exposed Subjects											
Subject	Age (years)	Gender	Work-Shift (hrs/day)	Work Days/Week	Daily Workplace PMP Listening Time (hrs)	Daily PMP Listening Time Before & After Work (hrs)	Daily PMP Listening Time, Days Off (hrs)	Duration of PMP Use (yrs)	PMP Used to Mask Workplace Noise?	PMP Used to Mask non-Workplace Noise?	Output Limiter Technology Used?
13	28	F	8	5	3.5	2.5	2.5	>5	yes	no	no
14	31	F	7	5	5.5	3	4	>5	yes	no	no
15	36	M	8	5	4.5	1	0	>5	yes	no	no
16	42	F	8	5	4	0	1	>5	yes	no	no
17	35	M	8	5	2.5	0	0	>5	yes	no	no
18	39	M	12	5	2	1	1	>5	no	no	yes
19	30	F	9.5	5	5	0	0	>5	yes	no	no
20	33	F	8.5	5	3.5	0.5	0	>5	yes	no	no
21	38	M	9	5	3	2	3	>5	yes	yes	no
22	43	M	10	5	4	0	1	>5	yes	no	no
23	41	M	9.5	5	2	0	0	>5	yes	no	no
24	40	F	8	5	1	0	0	>5	yes	no	no
Averages	36.3		8.8	5	3.4	0.83	1				

Table B.3: (Supplemental) Individual Listening Level and Background Noise Measurements, Exposure Estimates, and Signal-to-Noise Ratio for High Background-Noise-Exposed Subjects

High Background Noise Exposure											
Subject	FFLAeq Listening Level (dBA)	SLM Background LAeq Level (dBA)	Signal-to-Noise Ratio[a]	Work-Shift Listening Time (hrs)	Work-Shift Time not Listening (hrs)	Time Permitted at Listening Level[b](hrs)	Time Permitted at Background Level[b] (hrs)	Daily Exposure Estimate, % Dose[c]	Daily Exposure Estimate, TWA[d]	Background Only Exposure, % Dose[c]	Background Only Exposure, TWA[d]
1	84.9	87.7	-2.8	4	6	8.2	4.3	188.7	87.8	233.3	88.7
2	85.9	85.8	0.1	9	1.5	6.5	6.6	160.4	87.1	157.9	87.0
3	90.3	81.8	8.5	5	6	2.4	16.8	246.6	88.9	65.6	83.2
4	79.2	81.6	-2.4	3	7	30.5	17.5	49.7	82.0	57.0	82.6
5	83.4	74.9	8.5	0.75	10.25	11.6	82.5	18.9	77.8	13.3	76.2
6	88.7	81.8	6.9	1	9	3.4	16.8	83.0	84.2	59.7	82.8
7	88.3	81.3	7.0	5	6	3.7	18.8	166.3	87.2	58.5	82.7
8	87.8	81.8	6.0	5	5	4.2	16.8	148.8	86.7	59.7	82.8
9	95.2	88.6	6.6	3	7.5	0.8	3.5	610.3	92.9	301.5	89.8
10	85.3	73.8	11.5	3	8	7.4	106.4	47.9	81.8	10.3	75.1
11	72.3	77.5	-5.2	2	8	149.5	45.3	19.0	77.8	22.1	78.4
12	75.2	77.8	-2.6	6	5	76.5	42.2	19.7	77.9	26.1	79.2
Averages	84.7	81.2	3.5	3.9	6.6	25.4	31.5	146.6	84.3	88.7	82.4

a -The difference of FFL_{Aeq} *-* L_{Aeq}
b - Calculated using Equation 4.1.2 and Equation 4.1.1
c - Calculated using Equation 4.1
d - Calculated using Equation 4.2

Table B.4: (Supplemental) Individual Listening Level and Background Noise Measurements, Exposure Estimates, and Signal-to-Noise Ratio for Low Background-Noise-Exposed Subjects

Low Background Noise Exposure											
Subject	FFLAeq Listening Level (dBA)	SLM Background LAeq Level (dBA)	Signal-to-Noise Ratio[a]	Work-Shift Listening Time (hrs)	Work-Shift Time not Listening (hrs)	Time Permitted at Listening Level[b](hrs)	Time Permitted at Background Level[b] (hrs)	Daily Exposure Estimate, % Dose[c]	Daily Exposure Estimate, TWA[d]	Background Only Exposure, % Dose[c]	Background Only Exposure, TWA[d]
13	75.8	56.6	19.2	3.5	4.5	67.5	5660.3	5.3	72.2	0.1	56.5
14	86.4	56.9	29.5	5.5	1.5	5.8	5281.3	95.3	84.8	0.1	56.2
15	72.8	54.9	17.9	4.5	3.5	132.8	8383.5	3.4	70.4	0.1	54.8
16	69.1	58.6	10.5	4	4	312.1	3565.8	1.4	66.4	0.2	58.5
17	79.4	58.8	20.6	2.5	5.5	29.2	3404.8	8.7	74.4	0.2	58.7
18	65.5	55	10.5	2	10	726.0	8192.0	0.4	61.0	0.1	56.7
19	75.2	60.3	14.9	5	4.5	76.9	2407.5	6.7	73.3	0.4	61.0
20	76.7	61.9	14.8	3.5	5	54.1	1663.5	6.8	73.3	0.5	62.1
21	81.0	61.9	19.1	3	6	20.0	1663.5	15.4	76.9	0.5	62.3
22	81.0	58.7	22.3	4	6	20.1	3484.3	20.1	78.0	0.3	59.6
23	70.0	58	12.0	2	7.5	258.3	4096.0	1.0	64.8	0.2	58.7
24	66.5	61.6	4.9	1	7	578.5	1782.9	0.6	62.5	0.4	61.5
Averages	75.0	58.6	16.4	3.4	5.4	190.1	4132.1	13.7	71.5	0.3	58.9

a -The difference of FFL_{Aeq} - L_{Aeq}
b - Calculated using Equation 4.1.2 and Equation 4.1.1
c - Calculated using Equation 4.1
d - Calculated using Equation 4.2