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The effect of road noise on sound pressure levels and preferred listening levels using personal listening devices

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THE EFFECT OF ROAD NOISE ON SOUND PRESSURE LEVELS

AND PREFERRED LISTENING LEVELS

USING PERSONAL LISTENING DEVICES

by

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Abstract

Using a PLD in an automobile introduces unique threats such as volume levels set at higher levels to reduce the masking effects of road noise that enters the automobile. Passengers enjoying prolonged PLD exposure may be at an increased risk of noise exposure or fluctuating sound pressure levels resulting in hearing loss. Historically, hazardous noise has been primarily associated with industrial/occupational activities; however, harmful noise from recreational activities is also prevalent. The Center for Disease Control (2015) lists turning down PLD volume as one of their top three methods for reducing the possibility of NIHL in children. Excessive listening level and prolonged duration of use put listeners at risk for increased thresholds and other repercussions of hearing damage.

The combined effect of simulated road noise and PLD volume was measured in a simulated ear canal. The principal investigator collected all sound levels using KEMAR; no human participants. A pre-selected movie scene was delivered to KEMAR at normal listening levels through earbuds and headphones separately, while in the presence of road noise. The movie scene and road noise were increased in 5 dB steps and recorded.

The results showed earbuds are better designed for eliminating the masking effects of road noise, yet headphones are better designed for limiting the maximum SPLs. Frequent volume changes as high as 41 dB were reported in this study.

Key words: KEMAR, road noise, personal listening devices, sound pressure levels

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CHAPTER I

Introduction

The harmful effects of hazardous noise exposure are well documented, and efforts to warn and protect the public from these effects have always been a part of audiology professional counseling. Historically, hazardous noise has been primarily associated with industrial/occupational activities. However, harmful noise resulting from recreational activities or sociocusis may now be just as prevalent as occupational sources. In recent years, we have observed noise induced hearing loss (NIHL) occurring in younger and younger populations. A significant cause of NIHL identified in these younger populations is in the form of ear worn transducers. Researchers (e.g., Levey, Levey, & Fligor, 2011) link these changes in capability to changes in NIHL.

The Center for Disease Control (2015) lists turning down personal listening device (PLD) volume as one of their top three methods for reducing the possibility of NIHL in children. A PLD is a general term used to describe any device capable of presenting an audio signal to an individual for entertainment; this includes digital music players, cellular phones, smartphones, tablets, computers, portable disc players and other devices. PLDs do not cause people to become hard of hearing with recommended use; however, excessive listening level and prolonged duration of use put listeners at risk for increased thresholds and other repercussions of hearing damage.

Use of personal transducers has been commonplace and socially accepted in our society for the last few decades, specifically in the form of headphones connected to PLDs. In more recent years, PLDs have taken on newer, smaller forms, such as earbuds and headphones that are circum-aural. Additionally, the sound quality of PLDs has become better in more recent years, which has increased their popularity and use. The steadily decreasing size with equally increasing storage capacity of some PLDs has also led to significant rises in their popularity, and many PLDs are Wi-Fi accessible allowing users access to all content available on the internet. Depending on the type of PLD used, listeners can have access to their entire entertainment library at their fingertips.

Whether listening to music, audiobooks, smartphone application sounds, podcasts, videos, or movies many listeners, and this includes children, spend at least part of their day engaged with a PLD (Huang, Pawar, Hong, & Huang, 2011). The World Health Organization (2015) warns of the dangers regarding PLDs, and they advise people to monitor their audio exposure. They report approximately 50% of people 12-35 are exposed to excessive volume through entertainment such as PLDs. Though the bulk of PLD research is targeted towards pre-teens, teenagers, and young adults (Taljaard, Leishman, & Eikelboom, 2013), children as young as one-day-old newborns have been included in noise exposure research (Trapanotto, Benini, Farina, Gobber, Magnavita, & Zacchello, 2004).

The release and popularity of small portable entertainment devices, most notably the Apple iPod, sparked new research interest in portable noise exposure, specifically with PLDs. The iPod was marketed as being capable of storing large amounts of data, including music as well as videos. This welcomes the listener to stay connected to the PLD for extended period of times, (i.e., over an hour) without breaks. A less researched form of PLD that is also typically used for extended periods of time is a portable video player (PVP). A PVP is a PLD used to play digital videos, which are typically over an hour in length. They can also be in the form of a console type device which can be used to play video games. All of these innovations with PLDs and transducers have made portable/personal entertainment a readily available and preferable method of entertainment. Additionally, this appears to be most common place in younger listeners.

One listening situation in particular where this type of entertainment is most prevalent is in the automobile. This relatively new potential source of NIHL has been identified by researchers and practitioners of hearing health care. Sareen and Singh (2014) report shifting trends of increased use of mobile technology (such as PLDs) and more road noise in cities as two reasons why NIHL in younger people is becoming so common. While researchers are linking NIHL to headphones and road noise at a more significant rate than in the past, public awareness of this problem does not appear to be apparent.

The potentially compounding harmful effects of PLD use in automobiles are linked to noise abatement, ironically. Road noise is a known annoyance when traveling at highway speeds and there is large variability associated with the level of that noise. Factors affecting the variability of the noise level include the materials used to construct the interior of the car, the quality of the road surface, if the window of the automobile is open or closed, etc. Road noise that is encountered in the interior of a moving automobile is a relatively steady state low frequency noise which interferes with the understanding of speech, specifically consonant sounds. Listeners with PLDs commonly and quite naturally increase the playing level of the audio signal to compensate for this increased road noise/background noise that is introducing a masking effect. The obvious problem that is introduced when doing this is elevating the audio signal to a level that is hazardous and that can harm the listeners hearing.

Entertainment provided with automobile travel is a popular feature among almost all automobiles. From radios to PVPs, automobile makers are constantly upgrading their entertainment packages in an effort to make longer commutes more enjoyable to the driver as well as the passengers. Many automobiles offer the option of built-in video players, which are primarily used by children in the rear seats. The driver typically can control if the audio is played through the automobile speakers, or through a PLD worn by individual listeners. The benefit to the PLD in this scenario is that the occupants of the automobile can all listen to different personalized audio signals. A common use of this would be children in the rear seats viewing a movie that the adults may not choose to listen to.

As with other forms of PLDs, the danger of hazardous noise exposure is a potential threat. However, using video players as a PLD in an automobile introduces unique threats that are not as prevalent with other PLDs. One such threat is that volume levels used in a moving automobile may be set at higher levels in an effort to reduce the masking effects of road noise that enters the automobile. Taking this into account with the known broad amplitude fluctuations that occur in some videos, such as action/adventure, the listener may be placed more at risk for hazardous noise exposure.

Additionally, younger listeners such as small children may be unaware of the potential harm of the elevated listening levels, and supervising adults may be unable to monitor the elevated levels as well.

PLDs have greatly influenced the use of transducers and the age of the listeners who use them for extended period of times is becoming younger and younger. The composition of the portable transducer and PLD may vary, but their use leads to the same effects harmful effects if presentation level and extended use are not carefully monitored. Children may excessively use their transducers in terms of duration and level which leads to detrimental results such as NIHL and other related non-auditory effects. These problems may be particularly relevant for children in automobiles as the potential for unmonitored exposure is significant.

Literature Review

Noise-Induced Hearing Loss

NIHL is an acquired form of hearing loss and is characterized by a decrease in audibility coupled with an increase in hearing sensitivity thresholds. It is caused by exposure to excessive or hazardous noise which is characterized by the level or intensity of the noise as well as the duration of the exposure. Typically, this loss is observed in the higher frequencies (higher than 1000 Hz) and sometimes characterized by a pronounced dip or "notch" at 4000 Hz. The effects of excessive or hazardous noise exposure is often explained as causing hearing loss comparable to that of decreased sensitivity or hearing loss associated with advanced age. The hallmark of noise exposure is premature high frequency hearing loss (Naik & Pai, 2014).

Although NIHL is the second most common reason people become hard of hearing, NIHL is preventable through abatement (removing the noise or the listener from the noise) or personal protection (use of ear worn hearing protectors). Avoiding hazardous, excessive noise that surpasses noise exposure guidelines or wearing hearing protection in its presence can help prevent NIHL (Rawool & Colligon-Wayne, 2008). NIHL is one of several consequences facing people who exceed noise exposure guidelines. Other health, psychological, and safety concerns (that are non-auditory) have been linked to noise exposure through personal transducers, and the disregard for these concerns has led to shifting trends in audiological patient norms as a function of age. Noise exposure increases by level and/or duration can lead to NIHL as well as other conditions such as tinnitus a common symptom of NIHL and detractor of overall mental health. Ultimately, the user's health, cognition, and safety are all at risk for damage from hazardous noise exposure through the use of personal transducers.

National Institute for Occupational Safety and Health Guidelines

Personal transducers have been linked and are known to cause NIHL if they are used at higher than recommended listening levels and for prolonged durations (longer than an hour). Noise levels are deemed excessive or harmful by both the duration of the exposure and the intensity signal level. Intensity and duration have an inverse relationship meaning the greater the intensity, the less time for damage to the hearing system to begin (Naik & Pai, 2014). The National Institute for Occupational Safety and Health (NIOSH) in 2014 stated three rules to define excessive noise exposure: 1) The level of exposure cannot exceed 85 dB; 2) The decibel level of exposure is A-weighted, which means the signal at the speech frequencies, 1000 Hz – 4000 Hz, is emphasized over the signal at frequencies lower and greater than that range. A-weighted decibel measures are often noted as dBA; and 3) The duration of exposure cannot exceed eight hours per day. Duration also includes an exchange rate for levels exceeding 85 dBA. Table 1 further explains NIOSH's exchange rate.

Table 1. *dBA Exchange Rate*

Volume Level	Exposure Time
85 dBA	8 hours
88 dBA	4 hours
91 dBA	2 hours
94 dBA	1 hour
97 dBA	30 minutes
100 dBA	15 minutes

Note: dBA, or decibel A-weighted, is a unit of sound pressure used to account for loudness perception of sounds, and is commonly used for noise measurements.

Exceeding these guidelines places people at risk of permanent hearing loss. However, these guidelines are interpreted as occupational rules and not relatively associated with recreational or social noise exposure, even though the noise whether it is occupational in nature or recreational will have the same effect. The definition of "noise" should be noted in this context, as should the importance of the definition when dealing with recreational "noise" levels. Perhaps the term "noise" should be replaced with the term "sound" to better illustrate to the listener how the damage to hearing occurs, regardless if the sound is wanted or unwanted. To most listeners, noise infers some sort of unwanted sound, usually industrial or occupational in nature. The effects of NIHL can and will be encountered regardless of if the sound is wanted or unwanted, the level and the duration of the sound is what places a listener at risk.

To further complicate the problem, there are no readily available conversions or additional considerations for listeners who are generating the potentially harmful sound levels through PLDs. No such guidelines have been associated with personal transducers leaving users vulnerable to the consequences of excessive noise exposure. Though the NIOSH guidelines apply to anyone in contact with sound, the guidelines seem to be more readily applied to occupational than recreational noise. Current research result recommendations advocate for limited output from earphones, but researchers and developers may not account for duration of exposure (Fligor et al., 2014) in a meaningful way to sound that is encountered recreationally or socially.

People are typically aware that some types of sounds such as impulse or impact noise (a gunshot or explosions) and steady-state prolonged noise (such as jackhammers or lawnmowers) can cause hearing damage, but people may not realize that some normal or readily encountered forms of recreational or social noise such as the use of personal transducers can have the same negative and permanent effects (Davidson & Lutman, 2007; Levey et al., 2011; Idota, Horie, Tsutsui, & Inoue, 2010). Even more harmful is when personal transducers are used in place of noise or personal hearing protection. A common example would be an individual using their PLDs as a hearing protection, and furthermore at increased listening levels intending to block out the excessive noise of their lawnmowers.

Hearing protection is needed to attenuate excessive noise, yet some people choose to address the noise through elevated alternative signals, such as music (Idota et al., 2010). A layperson may ask, "How do I know if sounds are too loud or harmful?" The correct answer would be anytime people have to raise their voices to be heard by someone within arm's reach, they are at risk for excessive noise exposure and need to be wearing hearing protection (NIH, 2011). If people are exceeding the guidelines for noise exposure through use of their personal transducers, they are increasing the risk of noise induced hearing loss, regardless if the substituted sound is pleasing to them.

Auditory Effects

Increased hearing thresholds or the lack of sound detection are not the only problems associated with noise exposure. Exceeding noise exposure guidelines can lead to temporary or permanent problems with speech processing and discrimination, meaning some people can still hear speech but cannot understand what is being said. Other consequences associated with noise exposure include specific noise notches in their hearing sensitivity. A noise notch is a decrease in hearing sensitivity at a specific frequency, most commonly at 4000 Hz. Hearing sensitivity is notably better at the frequencies before and after the high-frequency dip. This decrease or noise is uniquely specific to NIHL but depending on how many years of exposure have been endured by the individual, it may not be present. Other auditory symptoms of NIHL include hyperacusis or oversensitivity to loud sounds, decreased balance and steadiness, decreased pitch perception, and recruitment or the phenomenon of sounds becoming louder than comfortable once threshold has been reached (Davidson & Lutman, 2007; Idota et al., 2010; Levey et al., 2012; Levey et al., 2011; NIH, 2011).

Although it is receiving more attention recently, tinnitus, or the perception of ringing in the ears, may still be overlooked in noise exposure research, even though it is noted tinnitus in almost seventy-five percent of NIHL cases (Gilles, van Hal, De Ridder, Wouters, and van de Heyning, 2013). They noted most participants did not believe their tinnitus could be caused by their personal transducers. Tinnitus from temporary threshold shifts cannot be measured though objective testing, yet changes in otoacoustic emissions can be noted immediately following noise exposure. Buckey et al. (2015) noted significant increases in patients' reports of tinnitus and decreases in OAEs for the higher frequencies after their patients had attended music concerts. A study by Zogby International (2006) stated teenagers were more likely to report experiencing tinnitus than adults, believed caused by their increased exposure to elevated recreational sound. Transducers are known to exacerbate this problem with hearing loss. Additionally, the harmful effects of NIHL extend past and are not isolated to deficiencies of auditory awareness; non-auditory effects of NIHL have also been reported and are significant.

Non-Auditory Effects

Noise exposure can also cause damage or pose health risks that may seem unrelated to the ears and hearing. Researchers (e.g., Bess et al., 1998) report that these effects can include but are not limited to decreased emotional stability, productivity, and academic performance. Decreased confidence is one of many social skills affected by hearing impairment. Zogby (2006) noted teenagers were more likely to report asking "what?" or "huh?" during conversations and after becoming aware of this habit, may choose to be silent and not request the missing information to be repeated. Hearing disability is known to negatively affect students' emotions and mental well-being. Noise and the consequences of excessive exposure can also cause stress, exhaustion, hypertension, and aggression in children.

Generalized anxiety disorders are common among children with hearing loss (Kim et al., 2012). These children may seem annoyed, and they may experience difficulty sleeping. Liu et al. (2013) also noted noise exposure can interrupt or alter sleeping patterns in young children. Although not as widely known, the non-auditory effects of hearing loss may ultimately pose a larger problem than just the loss of auditory information in and of itself. Audiologists and otolaryngologists note noise exposure is becoming a greater problem for more people, as well as younger people.

Many forms of noise can easily be removed or attenuated by the listener. However, road noise that is encountered by the occupants of an automobile are difficult to completely avoid, while at the same time maintaining one's alertness to sounds that should be carefully monitored for, such as sirens, horns, etc. Road noise as low as 55 dBA has shown correlation with heart problems such as strokes and coronary heart disease (Babisch, 2014). Exposure to high levels of noise has often shown a negative effect on the circulatory system in adults, and these noise-related heart problems are becoming more prevalent in children. Hasan, Begue, and Bushman (2013) tested the heartrates and levels of aggression of young adults playing video games. Their test involved allowing the winner to blast the loser with 60-105 dB of unpleasant noise through their headphones after a dual. The noise blasts was observed to increase the aggression level of their participants as they played the games. The authors observed that the whole body can become overworked and stressed when the auditory system is overstimulated by noise.

Though the previous study focused on college students, similar heart-related effects of noise exposure have been reported by other researchers. Liu et al. (2013) researched the effects of noise exposure on blood pressure in children and noted a direct relationship between increasing noise and increasing heart rate. They also noted an increase in blood pressure in infants, toddlers, and children when in the presence of excessive noise. Excessive noise has also been linked to altering muscle responses from nerves in newborn babies (Trapanotto et al., 2003). In this study, babies showed varying negative reactions to the noise exposure, and many babies showed signs of negative non-auditory effects even after the stimulus had stopped. These responses are a result of soundfield noise exposure. Noise exposure from ear level transducers would theoretically have a different effect even at similar intensities, as the in-ear effect of sound pressure would be greater.

Molesworth, Burgess, and Gunnell (2013) studied the effect of noise exposure through transducer use on academic performance. Their findings showed a 65 dB noise stimulator had the same effect as a blood alcohol concentration of 0.10. When surrounded by this excessive noise, their participants showed decreased scores on activities designed to test memory and recall. Noise exposure not only affects the physical performance of the body, but it can lead to temporary cognitive impairment. Wright, Peters, Ettinger, Kuipers, and Kumari (2014) highlight the effects of noise exposure as decreased attention, heightened stress, neuroticism and sleep disturbances all express how the additional mental stress of noise exposure can even lead to symptoms of schizophrenia.

Emerging Trends

Many people daily expose themselves to noise levels exceeding the guidelines set by The National Institute for Occupational Safety and Health (NIOSH) with PLDs. By listening to their PLDs too loudly and/or by listening too long, they are creating toxic noise environments for themselves. An oversight in NIHL guidelines/recommendations is the perception that NIHL is primarily an occupational hazard. As stated previously, recreational noise is not typically considered as harmful as occupational noise by most listeners, and reported activities and PLD use statistics show children are exposing themselves to more intense levels of sound now than in previous years (Henderson, Testa, & Hartnick, 2011). Even in 2006, thirty-four percent of their children participants reported listening to loud music through headphones within one day of the study. These numbers would probably be larger if the study was replicated today.

The impact of PLDs in more recent years has led to newer expectations of what may be seen in the hearing of younger patients that would once have been considered relatively rare. A new phrase appearing in NIHL research and counseling is "music-induced hearing loss" (Morata & Johnson, 2011). This hearing loss configuration resembles NIHL audiometrically; however, the cause is excessive music exposure at elevated levels for extended durations. As previously stated, noise as a definable term often reflects anything not wanting to be heard. Music-induced hearing loss indicates the sounds exceeding noise exposure guidelines were wanted and desired. In other words, the person was intentionally, but unwittingly, exposing their ears to these high volume sounds for great lengths of time. The music exposure may relate to either music from a live performance affecting musicians, disc jockeys, and audience members, or it could describe people casually enjoying their favorite music through their PLD.

A problem however with the phrase "music-induced hearing loss" is its exclusivity. The symptoms and conditions of this noise exposure also relate to people subjecting themselves to hours of loud surroundings for recreational events such as sporting events, parades, and movies. For example, Warszawa and Sataloff (2010) noted movie theater volume reaching 133.9 dBA. Though "music-induced" implies the cause of the NIHL was music instead of noise, the term could also be applied to any voluntary and pleasurable exposure to loud sounds for long duration as a pastime.

NIHL in Children. The CDC reports NIHL in nearly thirteen percent, or five million, of American children between six and nineteen years of age. Shargorodsky et al., (2010) reports an even higher increase in NIHL among children noting 16.4% of American children have at least a mild hearing loss in the high frequencies. They also observed that nearly twenty percent of children have a hearing loss as defined by either "unilateral or bilateral for low frequency (0.5, 1, and 2 kHz) or high frequency (3, 4, 6, and 8 kHz), and as slight loss (>15 to <25 dB) or mild or greater loss (≥25 dB) according to hearing sensitivity in the worse ear" (para. 15). Additionally, five percent of the tested children revealed hearing sensitivity greater than 25 dB. As Smith and White (2005) pointed out, these rising numbers of NIHL in children seem to counteract all of the positive changes in early identification of hearing loss at birth.

As suspected, this noise exposure problem is particularly prevalent in pre-teens and young adults. More than half of college students exceed noise exposure guidelines daily and are not taking preventative measures to protect their hearing (Levey et al., 2011, NIH, 2011). This noise exposure practice could be thought of as an ignorance regarding NIHL; however, Jones and Alarcon (2009) reported some of their participants were simply not worried about the risk. Of their participants, 23% reported they were not willing to turn down their listening level in an attempt to protect their hearing. Zogby (2006) noted teenagers were more likely to increase the volume of their television or radio than adults. This dismissive mentality among younger listeners has and is continuing to create new trends in people who are incurring hearing loss.

Older adults are traditionally thought of as the most likely to be hard of hearing and suffer from hearing loss disadvantages, yet new trends are showing teenagers and young adults as the most risk for NIHL. The future of this trend could lead to a new, lower mean age for hearing instrument users or new norms for threshold testing. LePrell et al. (2011) support the notion to increase the normal threshold average for young adults. The traditional norm for hearing is 0 dBHL, the audiometric zero, but audiological testing is showing 5 dB to be the new normal threshold for people age twenty or older. These threshold shifts were compared to the thresholds of industrial workers under similar excessive noise conditions by trade as young adults choose for their PLDs.

These trends show that within one decade these students are voluntarily exposing themselves to as much excessive sound and experiencing as much hearing loss as typically seen in men in their sixties (Levey et al., 2011). The CDC and NIOSH (2015) compared audiograms of twenty-five-year-olds exposed to traditional levels and durations of occupational noise and audiograms of fifty-year-olds who have either not been exposed to noise or have protected themselves from the harmful effects of noise exposure. The hearing thresholds are remarkably similar for such different lifestyles, demonstrating how harmful and permanent these negative effects of noise can be. Not limited to temporary threshold shifts, noise exposure, especially through unmonitored use of personal transducers, is beginning to cause permanent shifts in hearing loss norms. Instead of describing the hearing ranges beginning with "normal" meaning "typical," the thresholds may require rethinking in terms of "normal" meaning "undamaged."

Transducers

Transducers can alter loudness perception by the listener and result in an increase in volume to compensate. By surrounding the ear with a transducer or inserting the transducer into the ear, the sound pressure level (SPL) changes from the original shape of the ear canal in a soundfield. The sound pressure in the canal can also become stagnated causing a difference between the pressure in the ear and the pressure in the air. The sound pressure change is often due to attempting to block out ambient sound. The drawback to blocking out ambient sound is that people tend to block the sound by drowning it out. As the transducer volume increases, the risk of NIHL increases. As you occlude the ear, you increase SPL in the ear canal.

Different styles of transducers allow users to passively or actively form a relationship between the signal presented in the ear and the ambient sounds around the user. Research shows children are the most likely to be exposed to excessive noise through transducers, especially due to PLDs. Children are often noted as preferring louder listening levels, and their smaller ear size leads to more potential for damage because of increased SPLs. The prevalence of personal transducers has begun to change the trends in hearing loss such as the threshold norms and the mean age for hearing aid users. If transducer use patterns continue, audiological norms could shift with these changes. Personal transducers may be smaller in size, but their noise exposure damage should not be considered parallel.

Transducer Type. Headphone transducers vary in speaker size, speaker location, and fit for ears (Ciric & Hammershøi, 2006). Transducer headphones provide miniature loudspeakers to carry acoustical signals directly to the ear (Huang et al., 2011). They are generally divided into four categories or styles based upon their relationship to the pinna. Starting with the most exterior and working towards interior, the four categories are circumaural headphones, supraaural headphones, ear-fitting headphones, and in-ear headphones.

Circumaural are the largest type of headphones as they completely surround the pinna and suppress the ear canal. They either cup over the entire ear or use pads to suction against the canal opening. The tight fit of circumaural headphones provides the most secure, stationary headphones which retain their placement around the ears.

Circumaural headphones are often used for audiological hearing sensitivity testing because they are designed to attenuate air flow from outside the pinna to inside the canal. These headphones are calibrated according to standardized reference equivalent threshold sound pressure levels (Poulsen & Oakley, 2009). This calibration is mandatory for threshold accuracy. Supraaural headphones hold the padded speaker against the ear without creating suction. This style grew in popularity with personal stereos as a lightweight alternative to circumaural headphones (Huang et al., 2011).

The next two headphones styles press the speaker on or in the ear canal. Ear-fitting headphones, or earphones or earbuds, put the sound directly in the users ear canals. The usually uncovered speaker faces into the canal and fits in the concha bowl. The Apple iPod popularized the use of earbuds (Levey et al., 2012) as this design is more portable than headphones with headbands. Portability has become a great concern as more people are traveling with PLDs (Huang et al., 2011). Instead of a headband connecting the two phones across the head or around the back of the neck, earphones are held together under the chin by thin, plastic-coated cords. This feature allows users to more easily listen to music through only one ear if desired, but this style is often criticized for its propensity to fall out of the ear.

The last style of headphones is designed similarly to earphones except in-ear headphones fit inside the ear canal instead of the concha. This type is available in standard generic sizes or can be custom fit to ear canals with an ear impression. Another option is a customized adaptor which connects standard size earphones to a custom-fit earmold to carry the sound into the ear canal. The different styles of headphones offer options to suit the preferences of the individual wearer.

Transducer Features. Though comfort and portability are two important features of headphones, they are not the only options to consider when choosing headphone style. The person wearing the headphones and the materials used to make the headphones can also factor into differences in the signal presentation (Ciric & Hammershøi, 2006; Huang et al., 2011). Headphone styles also differ by the features each one presents to users. The design of each headphone style allows for changes in air pressure and ambient sound.

Pressure change. The relationship between the ear piece and the ear canal affect the air pressure in the ear canal, especially for low and high frequency sounds within the signal. The pressure changes can vary by transducer style, yet the sound pressure level in the ear canals may follow a relatively similar sound pressure level pattern inside the human ear; however, this shape of the sound pressure level differs greatly from the sound pressure level in an ear without any transducer affixed. The changes are more subtle in the mid and high frequencies, but the low frequencies showed great difference between the ear's natural pressure flow and the flow presented by the transducers (Ciric & Hammershøi, 2006).

The pressure changes will differ slightly from person to person based upon the individual makeup of the ear and how the headphone sits on or in the ear (Ciric & Hammershøi, 2006; Huang et al., 2011). Poulsen and Oakley (2009) noted the sound pressure level change was different for each frequency in the signal with the greater change being at 8000 Hz with approximately 0.5 dB difference from person to person.

The design of the transducer, specifically the miniature loudspeaker, can also affect the sound pressure level presented to the ear canal (Shiah, Her, Huang, & Huang, 2008). Signals presented through the speakers change the pressure in the canal. When the canal is not effectively sealed, the air pressure and thus sound pressure level can change. This pressure change is called leakage and can greatly affect the variability and reliability of audiological testing (Ciric & Hammershøi, 2006; Huang et al., 2011).

By sealing off the ear canal, circumaural and in-ear headphones create stationary air pressure inside the canal. Because in-ear headphones are placed inside the canal, they decrease the space inside the canal resulting in a pressure difference when compared to circumaural headphones. Supraaural headphones and earphones would seem to not affect ear canal pressure as much as the other two designs because the looser fit of these two styles should allow more pressure change as the air from outside the ear canal mixes with air from inside the ear canal. Yet Ciric and Hammershøi, (2006) noted supraaural headphones cause significant sound pressure level change within the ear canal.

Though the pressure changes can vary by transducer, the sound pressure level in the ear canals follow a relatively similar shape inside the human ear; however, this shape differs greatly from the sound pressure level in an ear without any transducer affixed. The changes are more subtle in the high frequencies, but the mid and especially the low frequencies showed great difference between the ear's natural pressure flow and the flow presented by the transducers. The greatest pressure change was shown using superaural headphones which presented changes of almost 20 dB compared to other transducers and the free ear (Ciric & Hammershøi, 2006). These pressure changes caused by transducer use explain the sensation of aural fullness which often coincides with extended transducer use. Personal transducer design should be considered for comfort and air exchange between the ear canal and the environment of the listener.

Noise reduction. Sound pressure level is not the only effect of transducer use in the ear canal. This air exchange also allows sounds from outside the ear canal to mix with the signal being presented to the ear. Another feature of headphone design is the amount of ambient or environmental noise blocked by the earpiece. Some headphones are designed to cancel out or attenuate ambient noise. Circumaural and in-ear headphones are designed to completely block outside noise, especially low frequency sounds such as road noise (Molesworth, Burgess, Gunnell, Loffler, & Venjakob, 2014).

Supraaural headphones hold the padded speaker against the ear without creating suction; therefore, supraaural do not attenuate as much sound. Supraaural headphones and earbuds provide the least amount of environmental attenuation. This might be considered a benefit or a drawback depending on user preference. These styles allow more ambient sound to enter the ear canal so people can focus on the environmental sounds and their music, but they may also lead to an increase in music level as a means to block out exterior sounds such as road noise (Jones & Alarcon, 2009). Some people may listen to music with the earphone in only one ear, leaving the other ear open for environmental or ambient sounds. By creating louder environmental sounds in one ear than the other, people may turn up their volume to hear the signal in the ear with the transducer. Increasing the sound level to compensate for ambient noise can become dangerous as listeners may not be aware of exactly how loud their sounds are becoming. "Given the proximity of the sound source to the eardrum, the threat of potential hearing loss through extended earphone use needs to be taken seriously" (Huang et al., 2012, p. 468).

60/60 Rule. Regardless of the type of transducer used, parent self-help resources such as TeenHealth by the Nemours Foundation and ParentalGuide.org offer the same rule of thumb for parents: use the 60/60 Rule. Pollard (2013) explains this rule is a simple guide for parents explaining they should only allow their children to wear headphones at sixty percent of the PLD volume for only sixty minutes at a time. Following the sixty minute interval, children should relax their ears for a brief period before continuing use. Though this rule seems relatively simple, parents may find it difficult to monitor their children's volume level. Children may be seated away from the parents in the back of the vehicle, children tend to learn how to adjust volume very early, and children may complain about not being able to hear over the increasing road noise.

Automobile Noise Exposure

A common noise exposure situation for children is traveling in an automobile. Whether watching a movie or listening to music, children routinely use PLDs in an automobile. Almost ninety-five percent of fourth grade students report having been exposed to dangerous volume levels in their lifetime, with seventy-three percent of these students identifying PLDs as the source of the exposure (Martin et al.,2013). Headphones were the most frequently cited source of noise exposure, followed by "riding in a car with loud speakers." These responses were more prevalent than guns, recreational vehicles, concerts, and heavy machinery. Having music in cars was designed to ease the solitude of driving, yet cultural shifts led to a desire for this solitude. People may tend to view their stereos as a way to block or tune out their surroundings, e.g., other drivers and road noise (Bijsterveld, 2010). As stated, one reason people wear personal transducers is to block or mask environmental noise (Levey et al., 2011). This masking carries over into people in motor vehicles attempting to block road noise. Airo et al. (2011) reported people adjusting their volume ten to fifteen decibels to compensate for the increase in road noise while inside a vehicle.

Road noise has been reported between sixty and eighty decibels (Levey et al., 2011), and listeners are increasing their personal volume through transducers to levels close to or exceeding the noise exposure guidelines from NIOSH. With the growing popularity of portable listening and viewing devices, especially tablets, passengers, specifically children in the backseat, can find solitude in the motor vehicle. Vehicles have begun catering to this trend by advertising the WiFi offered in vehicles. Vehicle manufacturers have responded to the backseat listener trend, and they have responded to the common knowledge of increasing volume as vehicle speed increases. Manufacturers are now including automatic volume settings to adjust volume at predetermined ratios for the MPH. An example is Honda's radio feature, the Speed-Sensitive Volume Control (SVC), which is available on a low, mid, high, or off mode depending on driver preference (Honda, 2015). This volume compensation feature and wi-fi availability are creating preferred listening environments for adults and children in the front or back seat of a vehicle.

An area of research yet to be explored is use of transducers in vehicles. Driving with headphones is against the law in most states; however, this law does not apply to passengers. People riding in vehicles or public transportation may feel the need to increase their personal volume to block out ambient noise (Levey et al., 2011), especially road noise. Passengers enjoying prolonged exposure of entertainment through their personal transducers may be at increased risk of excessive noise exposure or fluctuating sound pressure levels.

Most vehicles now promote optional headsets in cars for movie viewing by backseat passengers. Since these headsets target children, the effects of noise exposure could be more significant. If their volume is increased to compensate for traffic and they view movies for an extended length of time (e.g., road trips), children could exceed the National Institute for Occupational Safety and Health (NIOSH) limitations and cause noise exposure harm. Portable headphones are advertised with potential loudness just like home theater equipment. People could be exposing themselves to excessive noise while sitting in their homes or vehicles.

Statement of the Problem

The hazardous effects of elevated and extended exposure to noise, perhaps better stated as sound, is well documented and known. However, traditional thinking has limited the harmful effects of noise to that which is generated from occupational or industrial sources. These same harmful effects are sometimes not believed to occur from sounds that occur from recreational or social activities. Additionally, younger listeners may not feel they are susceptible to NIHL by virtue of their youth, or simply are not concerned with the potential permanent effects of NIHL. This trend is exacerbated by the prevalence of PLDs in our culture.

The most susceptible or at risk group of listeners for recreational induced hearing loss, or better known as NIHL, is young children as they are unaware of the risks and symptoms of excessive sound exposure and tend to prefer louder presentation levels. A common childhood experience where recreational noise may be presented at hazardous levels is while traveling in an automobile and using a PLD. Given that children are known to enjoy sounds at louder levels, and it is common practice to elevate the level of sounds presented through PLDs in the presence of increased background noise such as road noise, they are particularly at risk for hazardous noise or sound exposure. Therefore, the purpose of this project is to analyze how road noise of increasing intensity coupled with increasing the level of the PLD presentation increases SPLs in the smaller pediatric ear canal. Specifically, at what PLD listening level does sound presentation become hazardous in the presence of road noise.

CHAPTER II

Method

Experimental Instrumentation

The principal investigator collected and observed all sound levels obtained during the experiment using a G.R.A.S. Sound and Vibration Knowles Electronic Mannequin for Acoustical Research or KEMAR (45BB-5 Head and Torso for Ear- and Headphone Test, 2-Ch LEMO); no human participants were used in the study. The 45BB-5 KEMAR Head & Torso for ear- and headphone test, 2-Ch LEMO is an acoustic research tool with built-in ear simulators that simulates the changes that occur to sound waves as they pass a human head and torso. KEMAR fitted with pinna simulator, ear canal extension, and IEC 60318-4 Ear Simulator resembles the acoustic impedance of the human ear. Its corresponding CCP equivalent is G.R.A.S. 45BB-6 KEMAR Head & Torso for ear- and headphone test, 2-Ch CCP.

All experimental procedures were conducted in a sound-treated IAC booth (ANSI S3.1-1991) located in Woodard Hall on the Louisiana Tech University campus. Experimental equipment used consisted of a Grason-Stadler model 61 clinical audiometer (ANSI S3.6-1969), Grason-Stadler soundfield speakers(ANSI S3.6-1969) , and a Tascam CD-160 CD player. A Sony DVP-FX810 8-inch portable DVD coupled with Sony MDR-E9LP earbuds followed by Sony MDR-222KD children's headphones as the transducer was used to present the selected movie scene in the booth. The road noise simulation used during experimental testing consisted of a downloaded road noise sound file that was looped for continuous play. A Quest Electronics sound level meter (SLM) model 1700 (HT60-40004) was used to verify noise in dB SPL routed through the audiometer in dB HL (ANSI S1.4-1971), to monitor the movie volume, and to configure amount of volume increase when the DVD player was manually adjusted.

The feature film selected for this project was Walt Disney's Oscar-winning *Frozen* (2013). The scene selected for experimental manipulation was chapter eight, "Finding Elsa." This segment features dialog (quiet), a song (loud), and an action scene (loud) and provides a variety of volume fluctuations.

Experimental Procedures

KEMAR was placed in the center of the sound booth. A table in front of KEMAR held the portable DVD player. The pre-selected movie scene began with dialog, and the DVD player volume was set to the pre-selected most comfortable listening level (MCL) at 50 dB SPL and verified with the SLM. Every presentation was recorded through KEMAR using real-ear responses, first with the earbuds and then with the headphones at each volume setting. The same experimental design was used for the recordings of the earbuds and the headphones.

The SLM was used to monitor the sound levels played through the DVD player, and the audiometer presentation display ensured the noise simulation was at proper sound level, and verified with the SLM. Prior to data collection regarding road noise, the movie volume and sound pressure levels were recorded in the sound booth with the movie playing at 50 dB SPL to note frequency spectrum and amplitude range.

Initial presentation levels were based upon normative data from normal hearing listeners and MCLs. Real ear and free field sound level measurement were recorded. The intensity of the road noise and the presentation level were increased by 5dB and the same SPL measures taken. This scenario was repeated until road noise has reached 80 dB SPL. The initial starting level for the movie scene was 50 dB SPL to account for lower MCLs, and testing concluded at 70 dB SPL to stay within NIOSH noise exposure guidelines. See Table 2 for all recording levels. All presentations (movie scene paired with noise) were recorded twice to verify the reliability of the results.

Table 2. *Decibel Levels in the Noise Environment*

Movie Level	Noise Level
50 dB SPL	0 record
50 dB SPL	60 dB SPL
55 dB SPL	65 dB SPL
60 dB SPL	70 dB SPL
65 dB SPL	75 dB SPL
70 dB SPL	80 dB SPL

Note: In this table, "movie level" refers to the sound presentation at the beginning of the movie clip, and "noise level" refers to the amount of simulated road noise applied in the sound booth for the recording.

CHAPTER III

Results

The present study examined the effects of increasing sound pressure levels (SPLs) of simulated road noise on overall sound outputs of movie viewing when using earbuds and headphones connected to personal listening devices (PLDs) on KEMAR. The purpose of this study was to simulate and analyze how increasing the volume of a PLD when viewing a movie to compensate for the effect of increasing road noise, which would occur in a moving automobile, affects the overall SPL output recorded in the ear canal. All presentations settings were recorded twice to verify the reliability of the results.

Each presentation is referred to as a setting, which includes the movie scene volume level, road noise level, and the transducer worn by KEMAR. Each setting was recorded using earbuds, and then recorded using headphones. The initial movie volume was established as a root mean square (rms) average of the opening dialogue presented in the pre-selected scene. Movie volume was verified with a sound level meter to ensure proper volume increases. The initial setting consisted of the movie scene at 50 dB SPL with no simulated road noise presented to KEMAR. This was then repeated with the addition of 60 dB SPL of road noise, and then further repeated by increasing the movie scene volume and road noise by 5 dB SPL each until conclusion of the last setting which consisted of 70 dB SPL of movie scene and 80 dB SPL of road noise. Figures 1 through 12 show outputs in Pascals as recorded by KEMAR for each setting, twelve total. Time is reported in seconds. The approximate length of the movie scene was 420 seconds.

The output is presented in peaks, medians, and floors. Peak is the highest recorded level of output during each setting, median represents the midpoint of the output recordings for each setting, and the floor is the smallest recorded level of output during each setting. When presenting the movie at 50 dB SPL in the presence of no road noise, the transducers produced the same peak for the movie scene. The earbuds (Figure 1) presented slightly more sound remaining in the ear canal for the median and floor output when compared to the headphones (Figure 2).

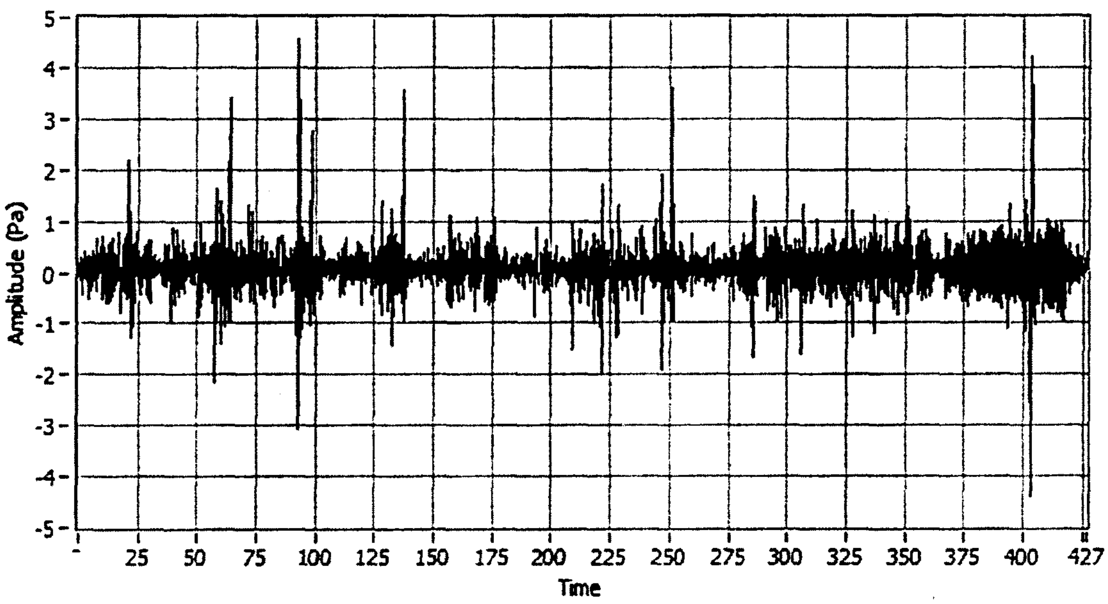

Figure 1. KEMAR sound pressure level (Pa) reading with movie volume at 50 dB SPL and road noise at 0 dB SPL using earbuds for the scene (in seconds)

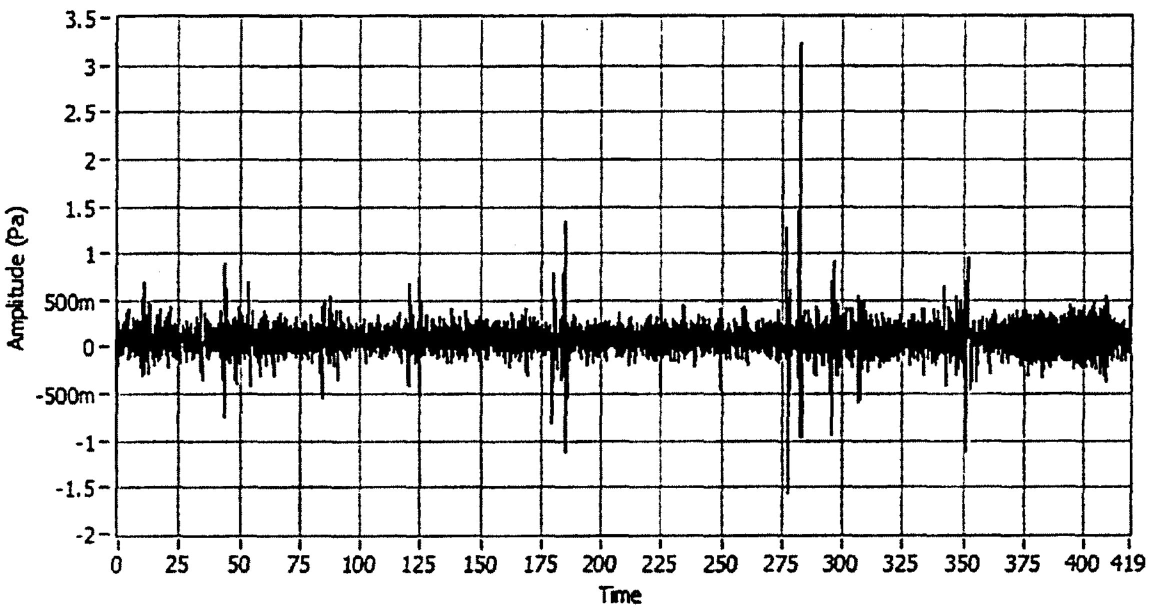

Figure 2. KEMAR sound pressure level (Pa) reading with movie volume at 50 dB SPL and road noise at 0 dB SPL using headphones for the scene (in seconds)

Now the outputs can be compared between transducers and with road noise. With the same movie level (50 dB SPL), road noise was presented at 60 dB SPL. The two transducers presented the same range of sound (lowest to peak), yet the earbuds (Figure 3) presented a greater peak, median, and floor. Again, the earbuds allowed less sound to escape than the headphones (Figure 4). Compared to the previous settings (50 dB SPL for movie and 0 dB SPL for road noise; Figures 1 and 2), the peak, median, and floor increased for both settings.

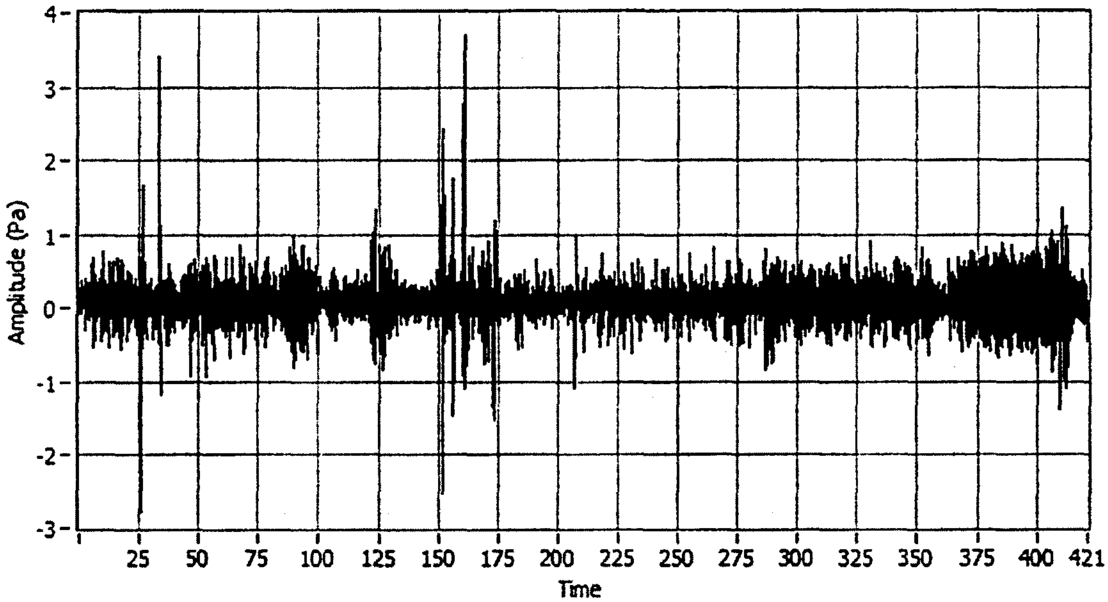

Figure 3. KEMAR sound pressure level (Pa) reading with movie volume at 50 dB SPL and road noise at 60 dB SPL using earbuds for the scene (in seconds)

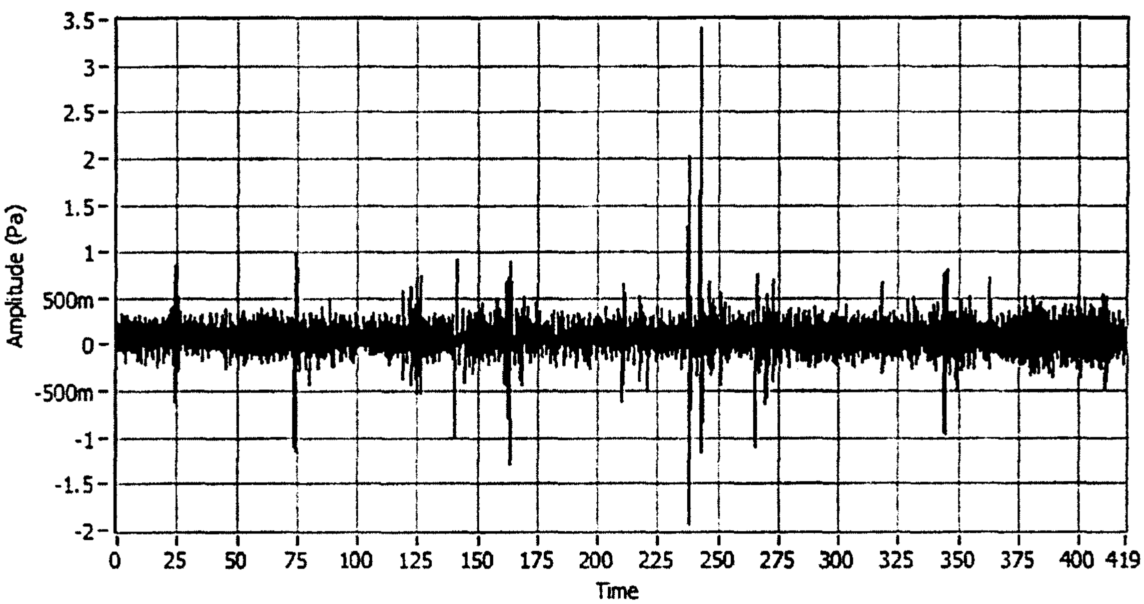

Figure 4. KEMAR sound pressure level (Pa) reading with movie volume at 50 dB SPL and road noise at 60 dB SPL using headphones for the scene (in seconds)

Now the outputs can be compared across transducers, with an increase in road noise presented, and with an increase in volume. The movie volume was increased by five decibels to a level of 55 dB SPL for the starting volume. The road noise volume was also increased by five decibels to a level of 65 dB SPL. The volume increases were monitored by using the sound level meter. In these settings, the earbuds presented a greater peak, median, and floor (Figure 5) than the headphones (Figure 6), and the earbuds presented a greater range of volume. The greater range of sounds is explained by the in-the-canal design of the earbuds. Earbuds allow less sound to escape the ear canal thereby creating a wider range of sounds than the headphones.

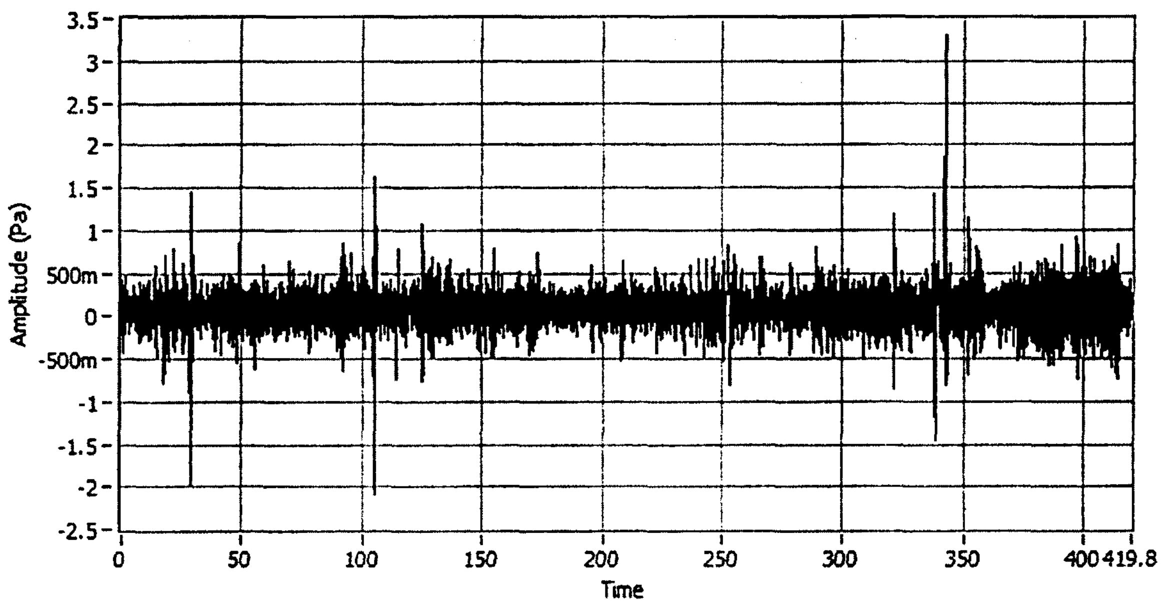

Figure 5. KEMAR sound pressure level (Pa) reading with movie volume at 55 dB SPL and road noise at 65 dB SPL using earbuds for the scene (in seconds)

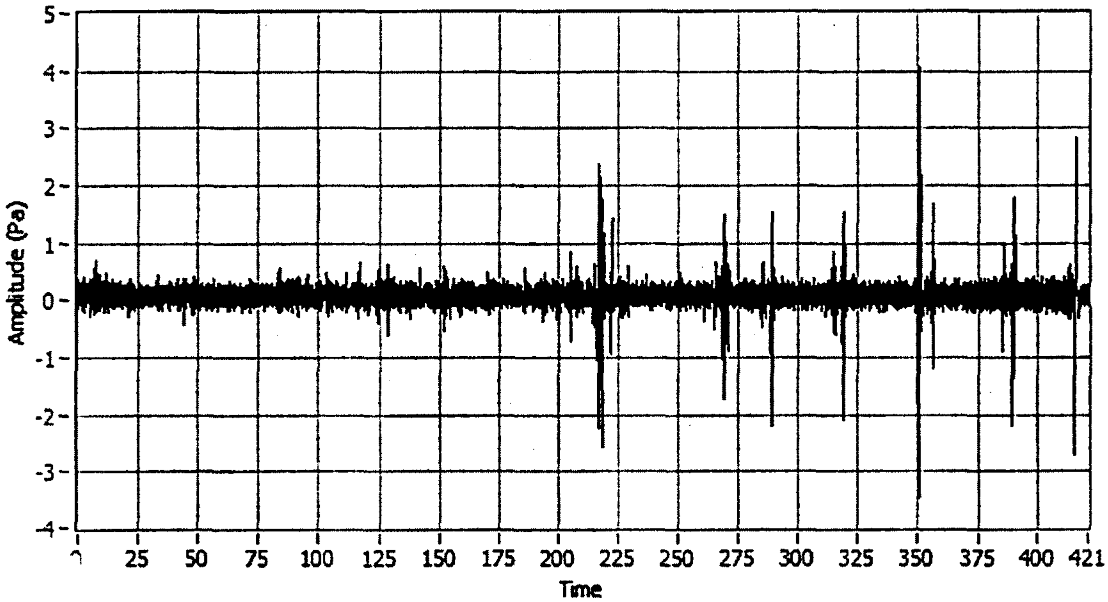

Figure 6. KEMAR sound pressure level (Pa) reading with movie volume at 55 dB SPL and road noise at 65 dB SPL using headphones for the scene (in seconds)

The movie volume and road noise were each increased by five decibels for the next round of settings, bringing them to 60 dB SPL and 70 dB SPL respectively. The earbuds (Figure 7) and the headphones (Figure 8) were recorded for these settings. These two settings mirrored the last round of settings (55 dB SPL movie volume with 65 dB road noise). Again, the earbuds presented a greater peak, median, and floor than the headphones, and the earbuds presented a greater range of volume. The headphones rest on the head allowing sounds to escape the ear canal.

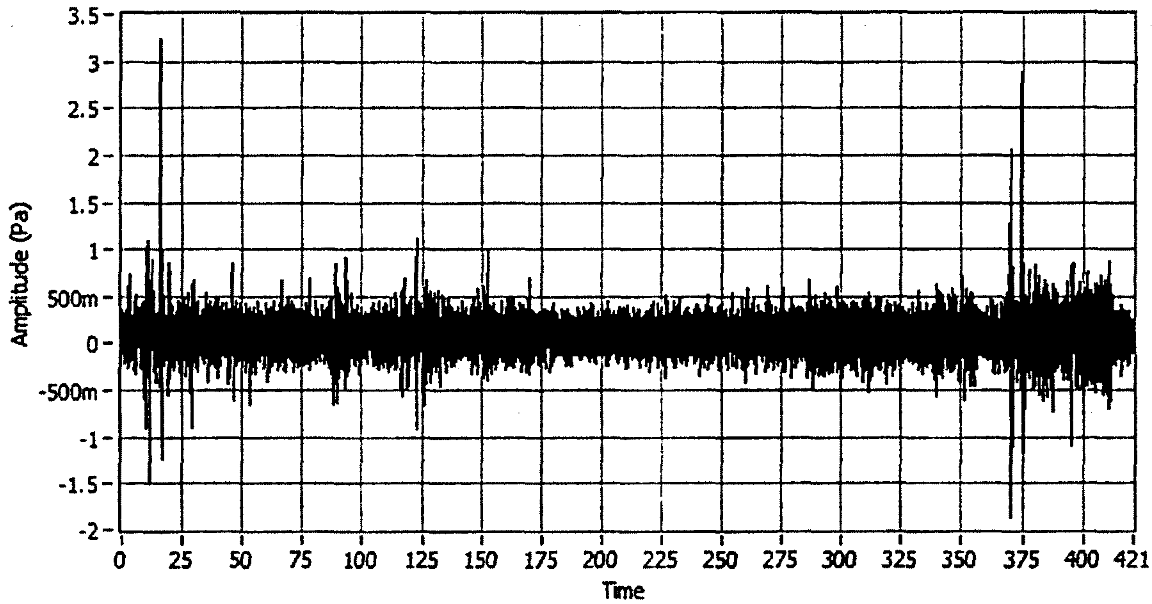

Figure 7. KEMAR sound pressure level (Pa) reading with movie volume at 60 dB SPL and road noise at 70 dB SPL using earbuds for the scene (in seconds)

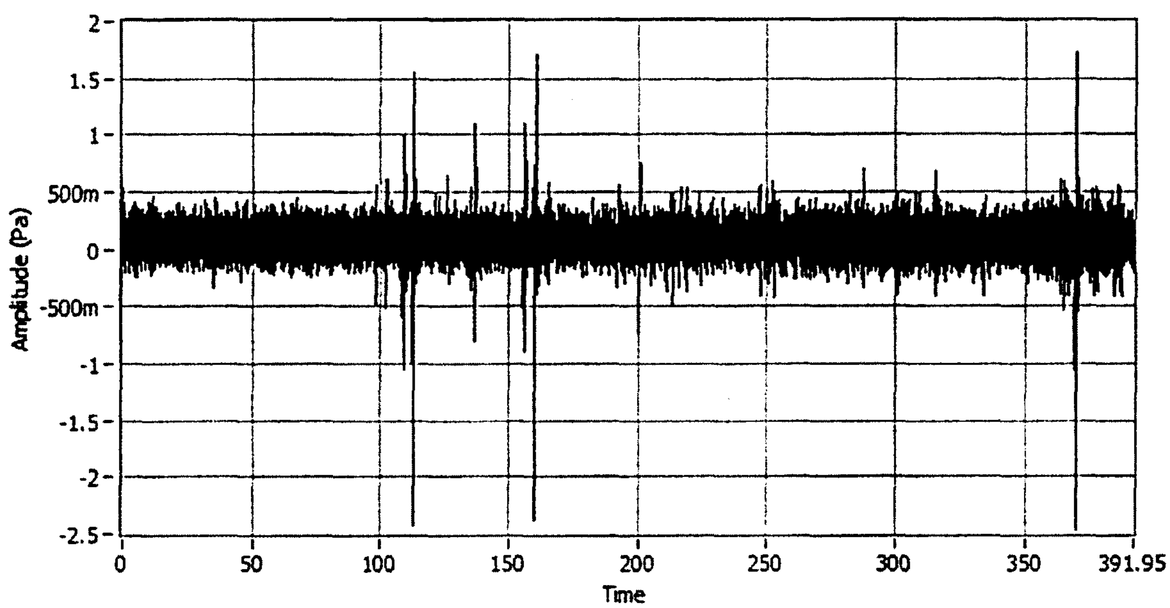

Figure 8. KEMAR sound pressure level (Pa) reading with movie volume at 60 dB SPL and road noise at 70 dB SPL using headphones for the scene (in seconds)

For the next two settings, the movie volume was increased by five decibels to a level of 65 dB SPL for the starting volume, and the road noise volume was also increased by five decibels to a level of 75 dB SPL. When wearing earbuds (Figure 9) KEMAR presented a lower floor than the headphones (Figure 10), meaning KEMAR retained more sound in his ear canals with the earbuds. In this setting, the earbuds presented a greater peak, median, and range than the headphones. By attenuating more of the road noise from entering the ear canal, the earbuds produce a lower level of movie volume.

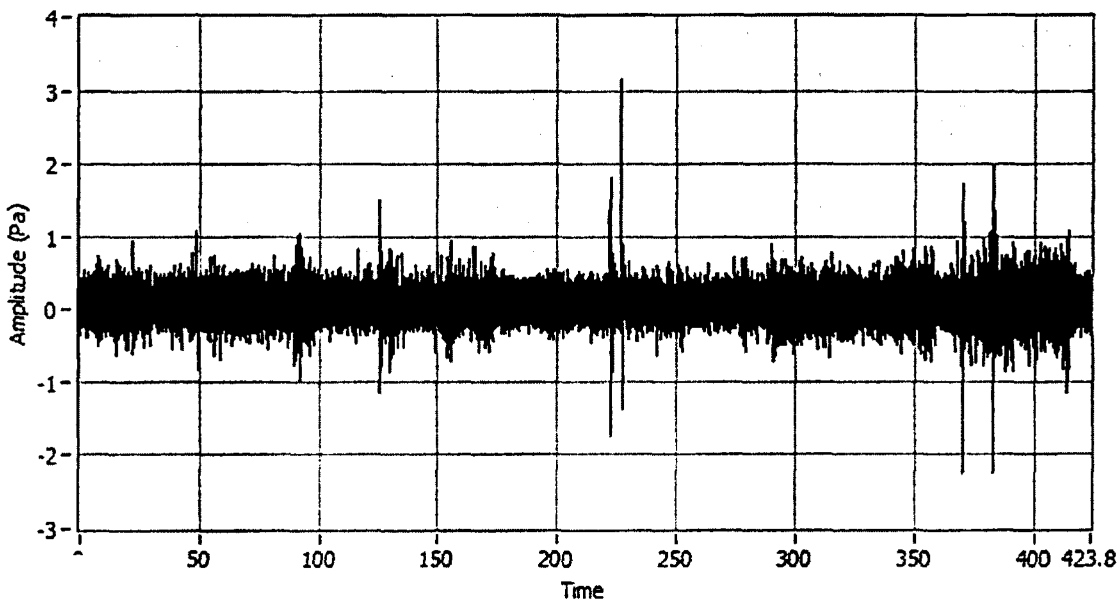

Figure 9. KEMAR sound pressure level (Pa) reading with movie volume at 65 dB SPL and road noise at 75 dB SPL using earbuds for the scene (in seconds)

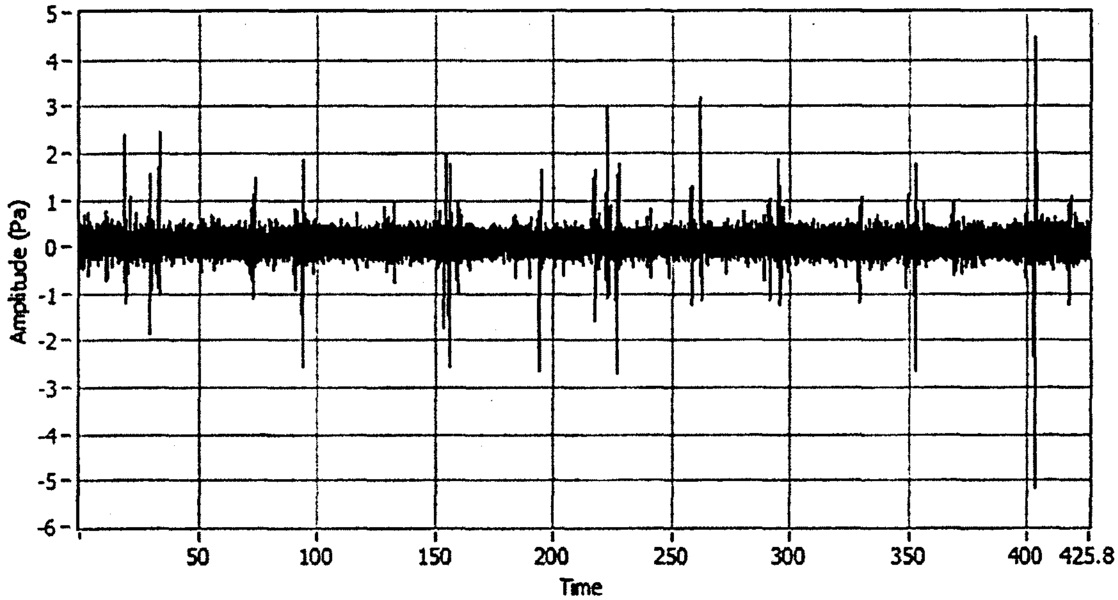

Figure 10. KEMAR sound pressure level (Pa) reading with movie volume at 65 dB SPL and road noise at 75 dB SPL using headphones for the scene (in seconds)

The two final settings increased the movie volume to 70 dB SPL and road noise to 80 dB SPL for the earbuds (Figure 11) and the headphones (Figure 12). When the road noise reaches and exceeds 75 dB, the headphones had a breakdown of attenuation abilities. The earbuds continued to decrease the sound presented to KEMAR below the road noise by sealing off the ear canal. The headphones allowed more road noise to enter the ear canal which prevented the movie level from decreasing as far as the earbuds. Again, the earbuds presented a greater peak, median, and range than the headphones.

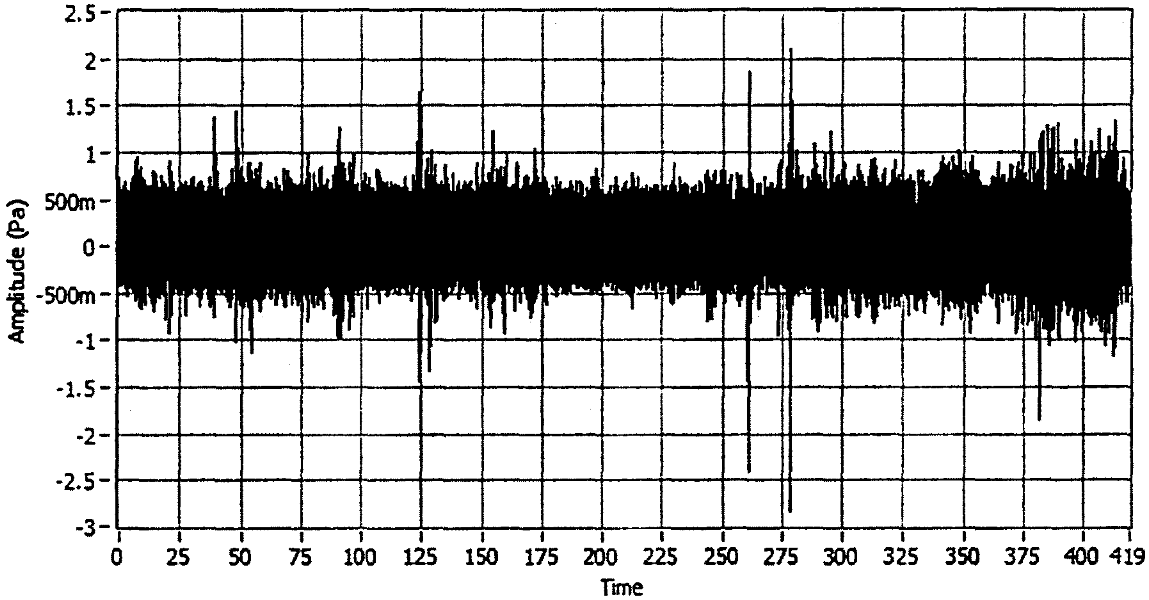

Figure 11. KEMAR sound pressure level (Pa) reading with movie volume at 70 dB SPL and road noise at 80 dB SPL using earbuds for the scene (in seconds)

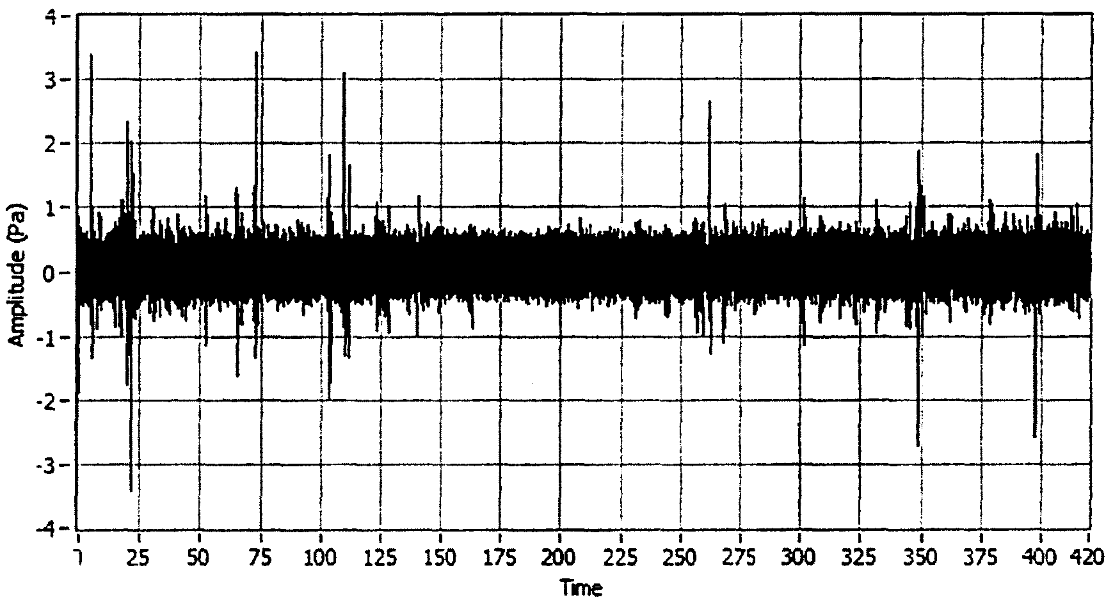

Figure 12. KEMAR sound pressure level (Pa) reading with movie volume at 70 dB SPL and road noise at 80 dB SPL using headphones for the scene (in seconds)

The next set of figures (Figures 13 through 17) displays the output recorded by KEMAR in decibels, as dB SPL is the most common unit of measurement for sound pressure level recordings. Figure 13 shows the output dB SPLs for the earbuds in terms of peak, median, and floor dB SPL as recorded by KEMAR. As expected, as the movie level was increased in the earbuds, the recorded SPL outputs, also increased.

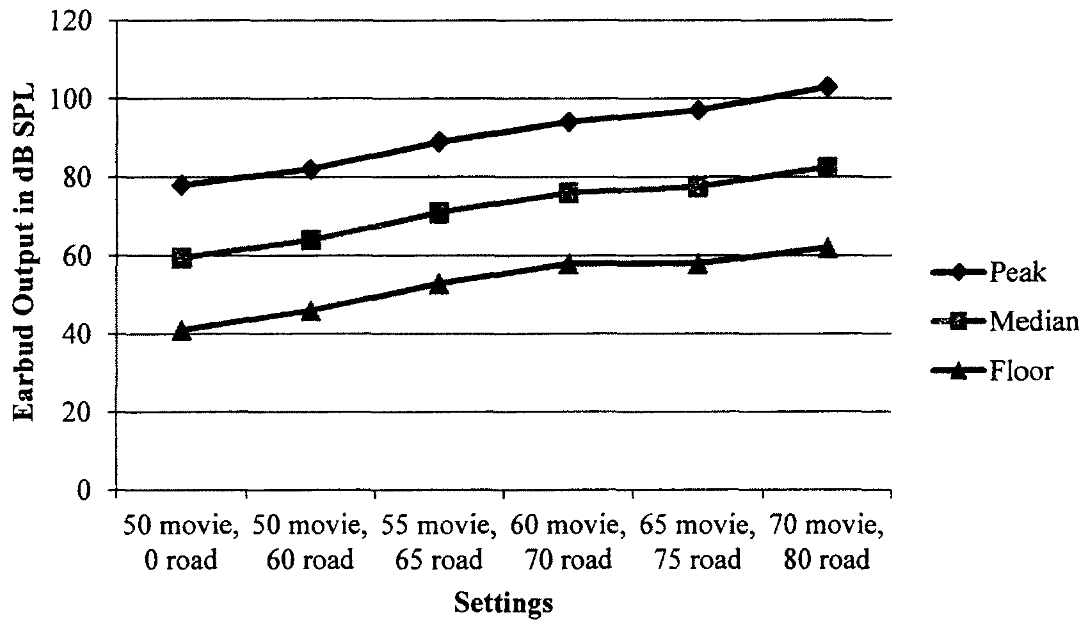

Figure 13. Sound pressure level peak, median, and floor as a function of movie volume (in dB SPL) and road noise presentation level (in dB SPL) for the earbuds

Figure 14 shows the output dB SPLs for the headphones in terms of peak, median, and floor dB SPL as recorded by KEMAR. In a similar pattern as the earbuds, as the movie level was increased in the headphones, the recorded SPL outputs also increased.

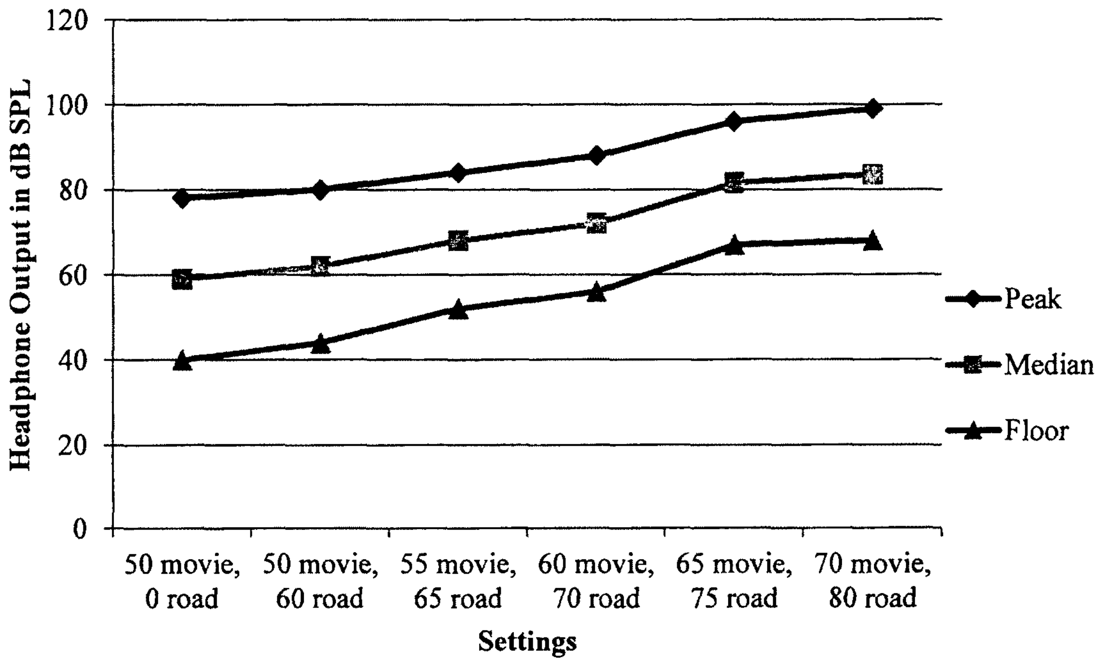

Figure 14. Sound pressure level peak, median, and floor as a function of movie volume (in dB SPL) and road noise presentation level (in dB SPL) for the headphones

Though volume was identically increased between settings for both transducers, the earbuds and headphones revealed different SPL readings. Figures 15 through 17 further break down the differences between earbuds and headphones by showing data comparisons between the two transducers.

Figure 15 shows the peak dB SPL output as recorded by KEMAR for each setting and for each transducer. The data illustrates the earbuds produced greater SPLs for the "loud" parts of the movie scene.

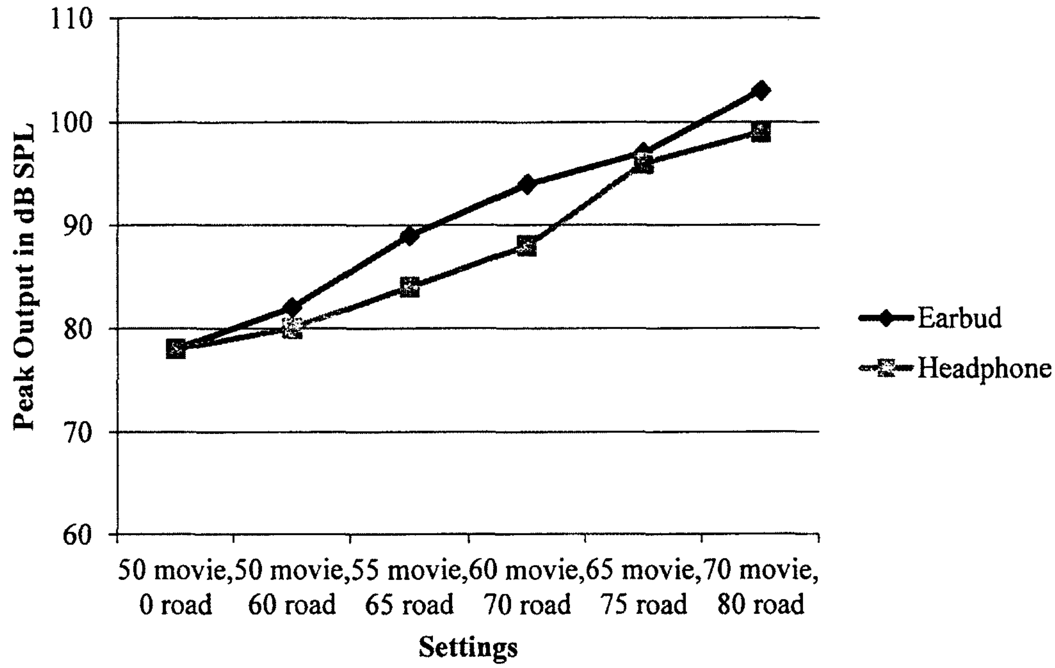

Figure 15. Sound pressure level peak as a function of movie volume (in dB SPL) and road noise presentation level (in dB SPL) for both transducers

Figure 16 shows the median dB SPL output as recorded by KEMAR for each setting and for each transducer. The earbuds produced greater volume ranges, variability, and medians for each setting. The earbuds were deeper-seated in KEMAR's ear canal and partially occluded the mannequin's ear canal. This design, as opposed to the headphones' design of covering the ear without inserting or encasing, allowed for less sound to escape the ear canal. This design ensured a greater amount of sound pressure stayed inside the ear canal and was presented to the ear.

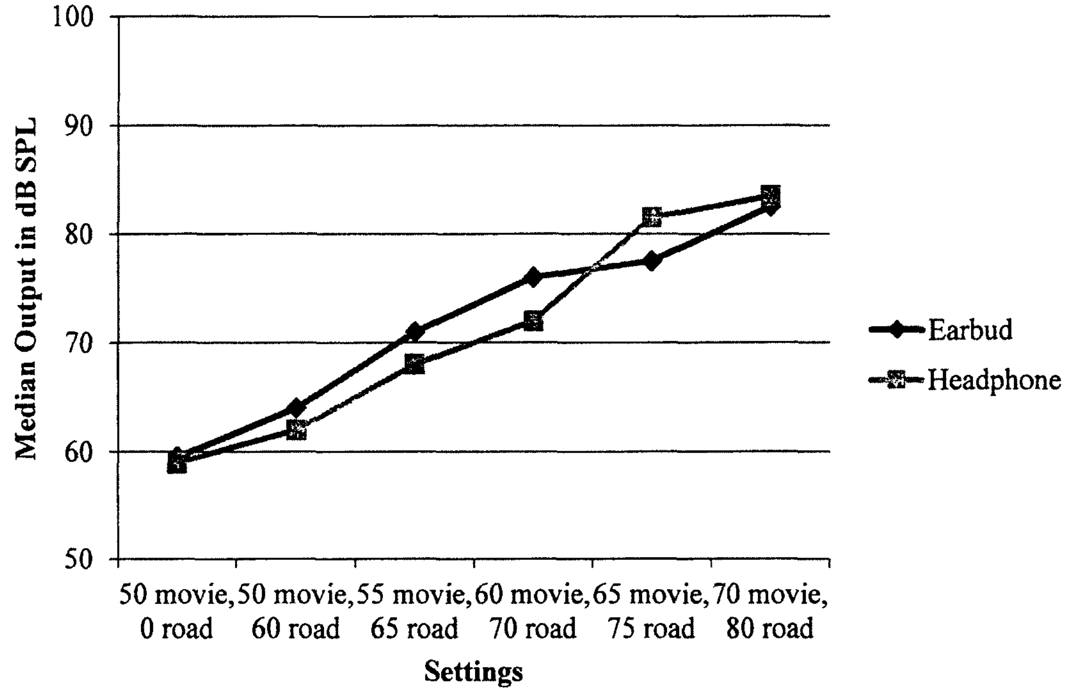

Figure 16. Sound pressure level medians as a function of movie volume (in dB SPL) and road noise presentation level (in dB SPL) for both transducers

Figure 17 shows the floor dB SPL output as recorded by KEMAR for each setting and for each transducer. Though the headphones did not present movie listening levels in SPLs as great as the movie listening levels produced by the earbuds (see Figure 15), the headphones allowed movie listening level output SPLs at lower levels than those produced by the earbuds. These results indicate that as movie scene presentation levels were increased to compensate for road noise, the earbuds attenuated more of the road noise than the headphones. The canal-occluding design of the earbuds allowed the movie listening level to decrease below the level of the road noise. In other words, the SPL outputs recorded with headphones did not attenuate the road noise presentation level as well as the earbuds did.

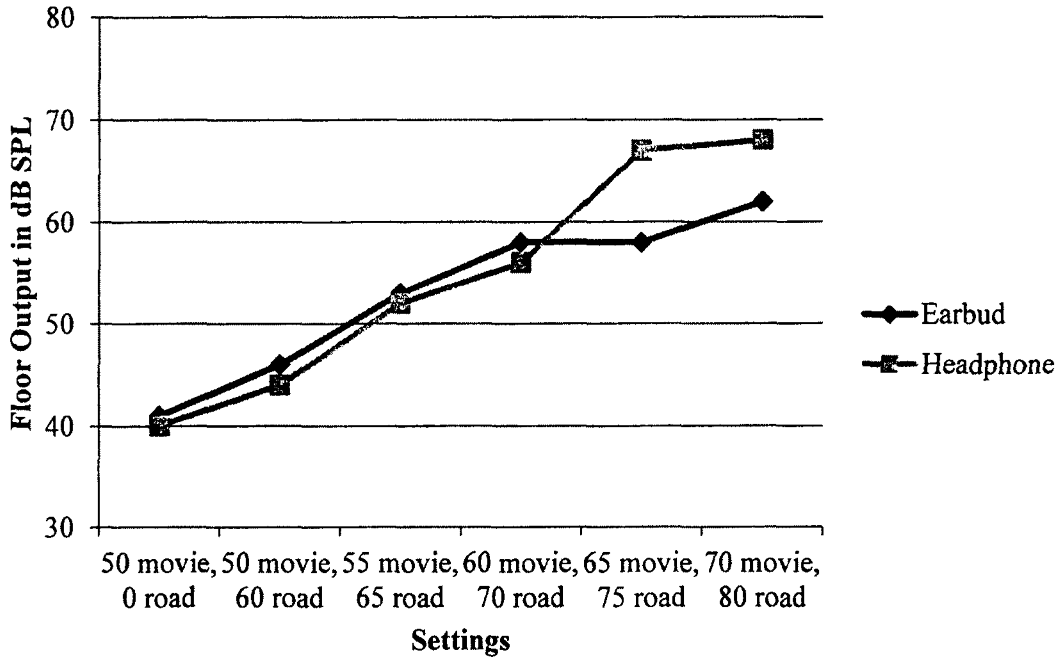

Figure 17. Sound pressure level floors as a function of movie volume (in dB SPL) and road noise presentation level (in dB SPL) for both transducers

The highest range presented at a movie level of 70 dB SPL with 80 dB SPL of road noise using the earbuds (range of 41 dB SPL). Additionally, Figure 14 shows the lowest range presented at a movie level of 65 dB SPL with 75 dB SPL of road noise using the headphones (range of 29 dB SPL). The lowest SPLs were recorded as the characters were talking to one another in a snowy, deserted environment. The highest SPLs were recorded during a song, as expected for noted volume increases during musical numbers (Warszawa & Sataloff, 2010). Elsa and Anna, the two main characters, were singing to each other, and Elsa raised her voice louder than her normal singing volume for the final note of the song to abruptly interrupt Anna. This final note was recorded at 103 dB SPL with the earbuds when the movie scene started at 70 dB SPL and the road noise presented at 80 dB SPL.

CHAPTER IV

Discussion

The purpose of this experiment was to observe and analyze how road noise of increasing intensity would affect the overall SPL output of a pre-selected movie scene if the presentation level were increased to compensate for the road noise. Additionally, would the overall output vary depending on the type of transducer? To answer these questions, KEMAR, wearing two different forms of popular PLDs, earbuds and headphones, was presented increasing levels of simulated road noise with increasing levels of the movie scene audio to determine if hazardous noise levels would be observed, and if so at what levels. Existing literature on noise exposure does not include studies that examine the changes in listening levels and SPL outputs in the presence of background noise that would be encountered inside a moving automobile when earbuds and headphones are paired to listening devices.

Disassociations exist when listeners consider the harmful effects of industrial or occupational noise as opposed to hazardous sound levels that can be encountered during social or recreational activities, such as listening to audio through ear level transducers like earbuds or headphones. Many individuals commonly perceive little or no risk to their hearing when they control the levels of audio presented through PLDs. Additionally, listeners tend to increase presentation levels when listening to audio through PLDs as time passes, and as background noise levels increases. Listeners may categorize elevated sound levels which are encountered voluntarily and controlled by themselves as something different than harmful noise, and may have no real concern as to the potential for hearing loss. Also, SPLs associated with movies are known to fluctuate significantly, with peak levels reaching intensities that would potentially result in NIHL with lengthy exposure times.

To simulate the type of conditions that might be encountered viewing a movie inside a moving automobile with earbuds or headphones, KEMAR was positioned in a sound-treated booth and presented increasing audio levels of a movie scene through earbuds and headphones, while at the same time exposed to increasing levels of road noise which were introduced through soundfield speakers. Specifically, KEMAR was presented with the movie scene audio at 50 dB SPL with no road noise, then with 50 dB SPL of movie scene audio and 60 dB SPL of road noise, 55 dB SPL of movie scene audio and 65 dB SPL of road noise, 60 dB SPL of movie scene audio with 70 dB SPL of road noise, 65 dB SPL of movie scene audio and 75 dB SPL of road noise, and finally 70 dB SPL of movie scene audio and 80 dB SPL of road noise. Each of these presentations or settings occurred and was recorded with earbuds and headphones for a total of twelve settings.

Results for the loudest sound levels presented to KEMAR, identified as impulse sounds in the movie scene, showed earbuds are capable of presenting a louder version of the same signal when compared to headphones. As earbuds are also closer to the eardrum than headphones, they should be able to produce a sound with greater SPL output that will not escape the ear canal. As the experiment shows, listeners wearing earbuds would most likely hear an increased volume range (or a greater difference between softest sounds and loudest sounds) due to the decreased air flow through the ear canal. The earbuds create a tighter seal within the ear canal than the headphones, and the sounds become trapped inside the ear canal more so than they do with headphones.

The results for headphones matched their design. By not completely sealing off the canal, road noise affected the minimum volume for headphones more so than it affected the volume for earbuds. The headphones reduce the impulse sounds because not as much SPL is retained in the ear canal. By aerating the ear instead of sealing it like the earbuds, headphones allow the potential damage of impulse sounds to diminish. By preventing a reduction and simultaneously an increase in sounds through attenuation, the headphones presented overall smaller volume ranges between settings. These results indicate headphones may be the safer option for listeners to wear due to the decrease in both sudden volume increases and reduced volume ranges; however, because headphones showed a greater effect for road noise, they may lead children to desiring a volume increase for understanding. The road noise may create a masking noise effect on listeners when using headphones preventing them from understanding the quieter scenes in movies.

Though not a research goal of this project, an observation worth noting is the volume perception differences between the two transducer types. As the recordings were established through KEMAR, the principal observer remained in the sound booth to monitor and verify the recordings and the noise environment for appropriate listening levels. From the observer's perspective, the movie volume appeared to be louder through the headphones than in the earbuds. The transducers were set to the same initial volume setting; however, the volume emitting from the headphones gave the impression of being set to a louder volume than the earbuds. This is worth noting because the earbuds were actually creating the louder sound pressure level.

Overall, earbuds may be the better choice for listeners as the wider volume ranges and SPL capacity indicate less of a need to increase the movie volume during a viewing. The results of this study showed that earbuds produced lower SPL output floors than headphones as presentation levels were increased to compensate for increased road noise levels. This could potentially indicate that earbuds may be better for blocking or attenuating the road noise, thus leading to lower ear canal SPL levels. This finding can be partially or potentially explained by noting the observable occluding/partially occluding of the ear canal that the proper fitting of the earbuds provide.

Limitations and Future Research

Though allowing observations to potentially harmful SPL outputs and differences over time, KEMAR created a limited simulation for this project. The experiments were conducted in a sound booth instead of an automobile, and the experiments were conducted on KEMAR as opposed to human ear auditory systems. Another design limitation was pre-selecting the volume and background noise presentations. Future projects regarding the effects of road noise on SPL outputs and preferred listening levels using PLDs should include live listeners and observe the preferred listening levels as road noise levels are increased.

Conclusion

An area of noise-induced hearing loss research needing more attention is the use of PLDs in automobiles. Automobile passengers may feel the need to increase their PLD volume in an effort to enjoy better speech understanding in the presence of road noise, particularly when wearing headphones. Passengers enjoying prolonged exposure of entertainment through their PLDs may be at increased risk of excessive noise exposure or fluctuating sound pressure levels that can result in permanent hearing loss. Additionally, children may be most at risk for this danger as their canals are smaller and therefore more affected by impulse sounds.

Earbuds are better designed for eliminating the masking effects of road noise, yet headphones are better designed for limiting the maximum SPLs presented to children's ears. No matter the transducer worn, parents should closely monitor the listening levels of their children. Parents cannot rely on the starting volume or their perception of overhearing the volume as safe methods for monitoring volume. Frequent volume changes as high as 41 decibels were reported for the movie in this study indicating parents need to cautiously observe all exposure through PLDs to ensure their children are listening carefully.

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