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Music-Induced Hearing Loss from Portable Listening Devices: Evaluating the Factors That Influence Risk Behaviors

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MUSIC-INDUCED HEARING LOSS FROM PORTABLE LISTENING DEVICES:

EVALUATING THE FACTORS THAT INFLUENCE RISK BEHAVIORS

by

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Music-Induced Hearing Loss From Portable Listening Devices: Evaluating The Factors That Influence Risk Behaviors

Thesis directed by Associate Professor Kathryn Arehart

This study investigated how people use portable listening devices (PLDs), such as MP3 players, through laboratory-based measures of chosen listening level (CLL), self-reports of listening habits, and with a field system for monitoring listening levels in real-world environments. Additionally, attitudes and beliefs about PLD use and hearing loss were assessed using the Listening Habits Questionnaire (LHQ), a survey based in the Health Belief Model.

The aims of this research were to 1) quantify and describe listening habits of PLD users, 2) evaluate the relationships between laboratory measures, self-report measures, and real-world measures collected through datalogging, 3) observe for effects of direct monitoring on self-reported listening habits and 4) evaluate the relationships between attitudes and beliefs about PLD use and hearing loss and listening behavior.

The listening habits of a group of 52 subjects with normal hearing, ages 18-29, were evaluated. Laboratory-based measurements of CLL in varying noise conditions showed that, as background noise increased, CLL increased, with 84.6 percent of listeners choosing levels above 85 dBA in the presence of 80 dBA of background noise. In contrast, field measurements over the course of a week identified that 16.7 percent of the study subjects accrued more than 100 percent of their weekly noise dose from PLD use. Overall, the study subjects tended to overestimate their exposure slightly, but were relatively accurate in their estimates of their PLD exposure. For all subjects, the most accurate question was one asking PLD users to report their listening duration and their usual listening level as a percentage of the volume control.

When attitudes and beliefs were compared to actual behavior, the strongest regression models were those predicting both self-reported and measured noise dose, showing much greater predictive value than those models predicting CLL alone. Further, an evaluation was completed of the LHQ showing good internal validity and reliability, positioning the LHQ to be used as a research tool for understanding the impact of attitudes and beliefs on listening behavior. This study also provides a novel technique for monitoring PLD listening levels over time, which could be adapted for future clinical or research use.

Dedicated in loving memory of my father, Colin, who taught me that knowledge, language and communication are critical to developing a complete person.

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GLOSSARY OF ACRONYMS

ANSI ....American National Standards Institute
CLL ....Chosen listening level
dBA ....Decibels, A-weighted
Dose ....Noise dose, calculated from one of the damage-risk criteria (such as NIOSH or OSHA standards). For example, 100% noise dose is equivalent to an 8-hour exposure at 85 dBA in the NIOSH standard
DRC ....Damage-risk criterion, In the noise-induced hearing loss literature, a theoretical framework for establishing the risk of hearing loss from exposure to sound over time. DRCs have been established by many researchers, governmental agencies (such as OSHA) and institutes (such as NIOSH)
EAECL ....Estimated ambient ear canal level, a level calculated by subtracting the measured earphone isolation from the known background noise level to provide an estimate of the actual background noise level in the ear canal with an earphone in place
EU ....European Union
HBM ....Health Belief Model
ISO ....International Standards Organization
L_{eq} ....Equalized level
L_{Aeq} ....Equalized level, A-weighted
$L_{Aeq,8hr}$ ....Equalized level, A-weighted, 8-hour exposure
LHQ ....Listening Habits Questionnaire
MIHL ....Music-induced hearing loss
MIRE ....Microphone-in-real-ear measurement
NHANES ......National Health and Nutrition Examination Survey
NIH ....National Institutes of Health
NIHL ....Noise-induced hearing loss
NIOSH ....National Institutes of Occupational Safety and Health, a part of the U.S. Centers for Disease Control
OAE ....Otoacoustic emission. Also, Transient-evoked otoacoustic emission (TEOAE) or Distortion-product otoacoustic emission (DPOAE)
OSHA ....Occupational Safety and Health Administration, a part of the U.S. Department of Labor
PCA ....Principle components analysis
PLD ....Personal listening device, such as an iPod or MP3 player
REL ....Recommended exposure level, a level denoted in the OSHA, NIOSH, or EU damage-risk criteria at which an 8-hour noise exposure is the maximum daily exposure level. For example, in the NIOSH standard, the REL is 85 dBA, at which an 8-hour exposure would accrue a 100% noise dose.
SNR ....Signal to noise ratio
TTS ....Temporary threshold shift
TWA ....Time-weighted average, or an average level that is extrapolated to an 8-hour noise exposure

CHAPTER 1: INTRODUCTION

As a public health concern, the influence of the use of portable listening devices (PLD) on music-induced hearing loss (MIHL) has been a recent topic of concern in both popular and peer-reviewed literature. At present, a significant body of literature has established that exposure to high levels of sound and music can have a substantial, damaging effect on the auditory system. Moreover, the current generation of PLDs are capable of producing high enough output levels to cause MIHL with extended exposure (Keith, Michaud, & Chiu, 2008). However, a high output level from a PLD will not necessarily cause hearing loss because both output level and the duration of exposure must be evaluated in order to assess the potential for hearing loss. To date, a small body of literature has identified that some, though certainly not all, PLD users have listening patterns that would put them at risk for developing hearing loss. Studies addressing patterns of use have implemented several methodologies to estimate sound exposure level and duration of use. For example, patterns of use have been measured with self-reports of behavior using surveys of typical listening habits (e.g. Danhauer et al., 2009). In addition, patterns of use have been measured in the laboratory or in naturalistic environments using recordings through probe microphones or manikins (e.g. Levey, Levey, & Fligor, 2011).

However, the current approaches to estimating patterns of usage are not without limitations. Self-reported listening levels, while providing a view of overall use, have been presented in several contexts but never validated. It is currently unclear whether self-reported volume control levels are reliable indicators of actual patterns of device usage. Measurements in the laboratory, while eliminating some of the response bias of self-reported listening levels, reflect an artificial environment that may or may not be related to listening levels in naturalistic environments. In addition, laboratory-based measurements do not have strong correlations to self-reported levels (Portnuff, Fligor, & Arehart, in press). Measurements of listening levels taken in naturalistic environments, such as when listeners are stopped on the street and measurements are taken, give an excellent snapshot of behavior, but may or may not be related to overall behavior across a person's daily life (Fligor, 2009). Unfortunately, the limited connections among these measurement strategies provide a somewhat muddied view of the actual behavior of PLD users, though there is a general agreement that a small but substantial percentage of listeners choose levels that increase their risk for MIHL (Levey et al., 2011; Torre, 2008; Williams, 2009).

While the risk of hearing loss increases with some patterns of PLD use, the factors that underlie these patterns of use remain unclear. Presently, the knowledge base regarding users' attitudes and beliefs about the overuse of PLDs and hearing loss is limited, in part due to a shortage of validated research tools for this purpose. Additional research examining how these attitudes and beliefs are related to listening behaviors is needed to help to understand why some listeners choose high listening levels. This study contributes to the development of a research tool, the Listening Habits Questionnaire (LHQ), which provides an avenue for examining these underlying factors. Formulated from the Health Belief Model (HBM), the LHQ provides a framework for examining relationships between beliefs about risky listening behavior and the actual behaviors. Previous work has established that the LHQ has excellent internal reliability and, in an initial group of teenagers, shows a strong relationship between attitudes and beliefs and a measure of self-reported listening behavior (Portnuff et al., in press). However, this research revealed that associations between the HBM construct variables on the LHQ and behavior measured in the laboratory were weak, though the same associations were much stronger between the attitudinal variables and self-reported measures (Portnuff et al., in press).

The apparent discrepancy between self-reported behavior and measured behavior creates questions about the current ways that behavior is measured. The LHQ includes a self-report of the listener's exposure as a behavioral measure, and due to lack of external validation of this metric, it is currently unclear whether the LHQ is evaluating real-world activity. In order to know that the LHQ is correctly assessing behavior, validation of the self-report measure is needed.

The first goal of this study is to characterize and describe how self-reported listening behavior is related to actual listening behavior, systematically evaluating the accuracy of a questionnaire in reporting actual behavior. In order to compare self-reported behavior to actual behavior, patterns of PLD usage must be monitored directly. This study uses a novel system for monitoring the use of PLDs over time by directly measuring the output of the device over an extended period to obtain accurate measures of actual listening behavior. The system uses a commercially available personal noise dosimeter with an input jack. However, no research to date has implemented this dosimetry system to measure PLD output levels over time. This study reports on the development of this new measurement system, including calibration and implementation in a research setting. To measure listeners' behavior over time, this study reports on a set of measurements taken over the course of a week for a group of young adults. These measurements are then compared to the listener's self reports regarding use of PLDs, implementing several metrics to determine how accurately the self-report questions reflect actual behavior.

In conjunction with the assessment of self-report, the study uses the LHQ to assess how attitudes and beliefs about hearing loss and listening behavior are related to both self-reported and actual behavior. With assessment of the accuracy of self-report measures, this study will be able to improve the interpretation of the results of the LHQ. Moreover, the addition of measured listening levels over time provide a novel approach to accurately measuring listening behavior and will provide an additional set of data that can be used to help understand the relationships between attitudes, beliefs, and listening behavior. Further, analysis of the results of this study reveals the most accurate self-report questions for representing actual behavior. The use of these questions in the LHQ will strengthen the external validity of the questionnaire, fine-tuning it and allowing it to be used more widely as an effective research tool.

CHAPTER 2: BACKGROUND AND SIGNIFICANCE

Reports in the popular media have suggested that young adults are at a high risk for acquiring hearing loss due to overuse of PLDs, such as MP3 players. However, further research is needed to help understand why some people put themselves at risk for hearing loss through recreational listening. In order to understand the effects of high levels of sound on humans, this paper begins with a review of literature about the effects of PLD use and an evaluation of the current knowledge base regarding how PLDs are used. First, to provide a background of how high sound levels cause an increased risk of MIHL, this paper presents a review of sound level measurement and the effects of music exposure, including PLDs, on the auditory system. Then, to specifically examine PLD overuse as a potential contributor to hearing loss, the current literature regarding both output levels and actual usage patterns across the population is evaluated. Several methodological concerns that make a significant impact in how the interpretation of this literature are also discussed, including issues in physical measurement of PLD output as well as concerns about self-report measures. This paper then provides a look at the larger perspective of why individuals might choose high listening levels. Finally, as little research has specifically examined what factors influence the listening behaviors of an individual, this paper considers how attitudes and beliefs about hearing loss and PLD use relate to listening behavior, providing a review of some potential psychosocial correlates of high-risk listening behavior.

Effects of music on the auditory system

With the exception of age-related hearing loss, noise-induced hearing loss (NIHL) is the most common form of acquired hearing impairment (NIH, 1990). A significant body of research indicates that adults exposed to high levels of sound for long durations are at a significant risk of hearing loss (Mencher, Gerber, & McCombe, 1997; J D Royster, 1996; Ward, Royster, & Royster, 2000). Damage-risk criteria (DRC), which indicate the risk to the adult worker of a given noise exposure level for a set duration, have been established by the National Institute of Occupational Safety and Health (NIOSH, 1998), the Occupational Safety and Health Administration (OSHA, 1981), and the European Union (EU, 2003). In a DRC, the recommended exposure level (REL) is set, representing maximum level at which a worker can be exposed for 8 hours a day. The REL is denoted using different terminology for each DRC, including as the permissible exposure level by OSHA, the REL by NIOSH, or the lower action exposure level by the EU. For each published DRC, the REL is different (80 dBA for EU, 85 dBA for NIOSH, and 90 dBA for OSHA). Further, a DRC includes a time-intensity trading ratio, or exchange rate, which represents the increment of decibels that results in a halving of exposure time. Again, each DRC sets its own exchange rate (3 dB for EU and NIOSH, 5 dB for OSHA).

The combination of the REL with an exchange rate creates a calculation that determines how long an individual can be exposed to a given sound level to reach their maximum daily exposure level. Conversely, with a given exposure time interval, an equivalent A-weighted sound level (L_{Aeq}) can be calculated. This level is often calculated for an 8-hour increment ($L_{Aeq,8h}$). An equivalent A-weighted sound level can be expressed in terms of a daily noise dose (in percent), where 100 percent noise dose is equivalent to eight hours of exposure at the REL. Noise dose is a cumulative measure, and exposures from individual activities in a given day can be added together to calculate a total noise dose. The DRCs range from the EU’s very conservative and most protective DRC to OSHA’s more liberal and least protective DRC. At present, no DRC has been developed specifically for evaluating music exposure, and the choice of which DRC to use for music is a topic of debate in the hearing conservation community.

In evaluating the risk of high sound levels, it is important to recognize the impacts of overexposure to music on the human hearing mechanism. Indeed, a large body of literature has identified both temporary and permanent effects on the auditory system that can be attributed to music exposure. At the population level, the prevalence of NIHL and MIHL can be estimated from large samples of children and young adults. As part of the Third National Health and Nutrition Examination Survey (NHANES III), Niskar and colleagues (2001) identified a subset of children who had audiometric hearing loss configurations that would suggest the presence of NIHL. Of the 5,249 children ages six to 19 years included in the national survey, 12.5 percent showed an audiogram notch at 3, 4, or 6 kHz, potentially indicating the presence of NIHL or MIHL. Extrapolation of these percentages to the entire U.S. population by the authors indicates that 5.2 million children likely have a high-frequency notch in one or both ears. The results from the NHANES III survey are somewhat higher than a similar, older study of 14,391 students in Sweden, where 2.3 percent of students had a hearing loss at 4 kHz, with 63 percent of those losses being potentially attributable to high levels of sound exposure (Rytzner & Rytzner, 1981). While these epidemiologic interpretations provide a rationale for MIHL prevention programs for children, using a high-frequency audiogram notch as a diagnostic indicator of MIHL is potentially misleading. Though a high-frequency notch is often suggestive of sound over-exposure, this configuration of hearing loss may also be due to other etiologies. In a large sample of adults, Oseh-Lah and Yeoh (2010) found that 40 percent of a clinical population had a high-frequency notch that could not be attributed to a history of noise exposure. Furthermore, Schlauch and Carney (2011) suggest that some of the audiometric noise notches identified in the

NHANES data may be due to systematic calibration errors, and that the false-positive rate within that data set may be unacceptably high. Thus, the prevalence estimate of hearing loss due to sound exposure in the Niskar et al (2001) article must be interpreted with caution.

Looking more specifically at MIHL, groups of musicians have been identified as at risk for acquiring noise-induced hearing loss. In a group of musicians in the Chicago Symphony Orchestra, Royster, Royster and Killion (1991) found a notched audiogram consistent with MIHL in 52.5 percent of the performers. Within that group, hearing thresholds were correlated with noise exposure measured by dosimetry, suggesting that decreased hearing thresholds may have been related to the exposure of the musicians. In a similar study, Emmerich, Rudel, and Richter (2008) identified that more than 50 percent of a group of 109 professional musicians had hearing worse than 15 dB HL. In that group, the authors identify musicians playing brass and stringed instruments as having the worst hearing thresholds, and that older musicians had greater degrees of hearing loss on average than younger musicians. The authors noted that the hearing thresholds in middle-aged musicians exceeded age-matched non-exposed ears. Moreover, the entire orchestra accrued or exceeded a 200 percent noise dose for an 8-hour exposure, using German standards, which are similar to NIOSH DRC. The authors concluded that music-induced hearing loss (MIHL) should be treated as an occupational disease (Emmerich et al., 2008). Similarly, in a group of music students, Phillips, Henrich and Mace (2010) identified 15 dB high-frequency notches in the audiograms of 45 percent of students, with 12 percent of students showing a bilateral noise-induced hearing loss. Across the literature looking at the hearing thresholds of musicians, it is clear that the prevalence of hearing loss increases with overall exposure time for musicians, with older professional musicians showing worse thresholds than younger musicians and students (Emmerich et al., 2008; Phillips et al., 2010).

Several researchers have used survey measures to evaluate the prevalence of auditory effects of music on specific groups of music listeners. Holgers and Pettersson (2005) surveyed 13 to 16 year old students in Sweden and identified that 52 percent of students had experienced a temporary hearing threshold shift (TTS) after exposure to loud sound, and 35 percent of the students experience TTS sometimes or often. Amongst this group, the risk for experiencing either noise-induced or spontaneous tinnitus was greater for students who reported an increasing numbers of TTS events. In a large survey of adults in urban areas of Helsinki, Finland, nine percent were judged to be exposed to leisure noise greater than 85 dBA, and that tinnitus and self-reported hearing loss correlated with increasing leisure noise dose (Jokitulppo & Björk, 2002).

In nightclubs, both attendees and employees have been surveyed regarding symptoms of auditory effects of noise. Meecham and Hume (2001) found that 87 percent of university students in Manchester, England had attended nightclubs and that 80 percent of attendees had experienced tinnitus upon leaving the venue. A significant association between frequency of nightclub attendance and the duration of the tinnitus was identified. A similar association was identified between tinnitus duration and use of illegal drugs at nightclubs, though the authors suggested that the primary factor affecting tinnitus duration was frequency of nightclub attendance (Meecham & Hume, 2001). Similarly, a survey of employees in urban nightclubs found a significant positive relationship between duration of employment and presence of tinnitus at the end of a work shift (Gunderson, Moline, & Catalano, 1997). Fifty-five percent of nightclub employees reported that they perceived their hearing to be worse since becoming starting work at a nightclub and employees in louder nightclubs reported more tinnitus and hearing loss after work than employees at quieter nightclubs (Gunderson et al., 1997). For employees in nightclubs or discotheques, MIHL should be considered an occupational hazard, and hearing loss prevention programs should be considered for employees at risk for MIHL.

In order to show specific auditory effects of music exposure in more controlled studies, a body of literature has evaluated the effects of single exposures on various biomarkers of auditory system function, including distortion product otoacoustic emissions (DPOAEs), transient-evoked otoacoustic emissions (TEOAEs), tinnitus and TTS. Torre and Howell (2008) evaluated a group of 50 participants in aerobic exercise classes in which mean levels ranged from 83.4 to 90.7 dBA. In this group, the researchers found a significant decrease in average DPOAE levels at 6000 Hz at the end of the aerobics class compared to the beginning of the class. Decreased OAE levels is indicative of damage to cochlear outer hair cells, a commonly identified effect of noise exposure in human temporal bone studies and in animal models (Rask-Andersen, Ekvall, Scholtz, & Schrott-Fischer, 2000). In a more controlled condition, Keppler and colleagues (2010) exposed participants to one hour of music at 50 and 75 percent of the maximum volume of an iPod, as well as one user-controlled level that was at least 75 percent of maximum volume, but as high as the users preferred. The authors found a significant increase in the incidence of significant hearing threshold shifts at 4000 Hz when the listeners used earphones at 75 percent and higher. Additionally, significant decreases in TEOAE levels were seen in the higher sound exposed conditions at 2.0 and 2.8 kHz. Though the differences identified in both of these studies were functionally small, significant changes in OAE levels suggest that some damage to the outer hair cells occurs due to music exposure alone.

Several studies found little or no changes in OAE levels and hearing thresholds following exposure to music. Bhagat and Davis (2008) identified small but significant changes in DPOAEs following a 20-minute exposure to earphones playing at 85 dBC at the eardrum.

Though only small decreases in DPOAE levels were noted by the researchers, the listeners' overall sound exposure was likely quite low. Considering that music stimuli tend to have a significant amount of energy in the lower frequencies (Hétu & Fortin, 1995), music played at 85 dBC will likely be below 85 dBA, as an A-weighting filter removes more low frequency information than a C-weighting filter. Furthermore, the measurements in this study were taken from the ear canal without transformation to diffuse field levels. A significant reduction in level would occur if these measures were transformed to diffuse-field equivalent levels. Overall, the noise dose for the listeners in this study likely was negligible, and thus it is not surprising to see only small changes in DPOAE status. Looking at higher levels of exposure, a similar study by Krishnamurti and Grandjean (2003) did not find differences in hearing thresholds or DPOAEs following 20 minutes of exposure to music at 90 to 95 dBA. However, the overall exposure of these participants was lower than the exposure of the participants in the Torre and Howell (2008) study. Moreover, a participant exposed to 95 dBA for 20 minutes would receive a less than 100 percent noise dose using NIOSH damage risk criteria.

Tinnitus has also been used as an indicator of damage to the auditory system following music exposure. Surveys of listeners following exposure to music have found substantial groups of people report having experienced tinnitus following exposure to high levels of sound at concerts and following PLD uses. In several large, internet-based surveys of youth and young adults, over 75 percent of respondents reported having experienced tinnitus or trouble hearing following a concert (Chung, Des Roches, Meunier, & Eavey, 2005; Quintanilla-Deck, Artunduaga, & Eavey, 2009). With a slightly lower prevalence, Holgers and Pettersson (2005) found that 51 percent of a large sample of Swedish adolescents had experienced tinnitus following a concert, and 58 percent of adolescents had experienced tinnitus following attending a discotheque or club. In a large music festival, Mercier, Luy and Hohmann (2003) reported that 36 percent of a sample experienced post-exposure tinnitus. These reports of tinnitus following exposure to music at concerts and discotheques help to illustrate the significant effect of high music levels on the auditory system.

The prevalence of temporary hearing threshold shifts (TTS) following exposure to high levels of music is perhaps the most compelling biomarker that is suggestive of the auditory effects of music exposure. Opperman and colleagues (2006) systematically evaluated audience members for hearing threshold shifts following several concerts with average exposures ranging from 95 to 107 dBA. In this small group of audience members, 64 percent of participants showed a TTS. In a similar group of audience members wearing earplugs, only 26 percent of ears showed a significant TTS using the OSHA definition of hearing threshold shift, which is an average decrease of 10 dB or more at 2000, 3000, and 4000 Hz. The presence of TTS and the significant effect of earplug use in this group underscore the significant effect of high levels of music on the auditory system.

In an expansion of the use of TTS as a marker for noise-induced physiologic change in the auditory system, Strasser, Irle and Scholz (1999) compared the physiological cost of exposure to various sounds on the auditory system. The authors define physiologic cost in terms of integrated restitution temporary threshold shift (IRTTS), a metric created by computing the integral of the regression function of TTS from two minutes post-exposure to the time of complete resolution of the TTS. Following the exposure of participants to one hour of white noise, industrial noise, heavy metal music and classical music, Strasser, Irle and Scholz (1999) concluded that the IRTTS was not significantly different between industrial noise and heavy metal music. However, both exposure to industrial noise and heavy metal music caused an

IRTTS that was 50 percent higher than that caused by exposure to white noise. Further, exposure to white noise created a 38 percent higher IRTTS than that exposure to classical music, with the IRTTS of classical music falling to approximately one quarter of that experienced with industrial noise and heavy metal music stimuli. Under a similar paradigm, Strassler, Irle and Legler (2003) identified that classical music has a significantly lower IRTTS than industrial noise, even when presented as energy-equivalent average sound pressure levels. The authors suggest that this reflects the characteristics of classical music as being more variable, unlike industrial noise which is a more stochastic signal with a smaller dynamic range and which has a higher prevalence of periods of high levels.

Auditory system dysfunction attributed to use of PLDs

Beyond the general findings that music can have a significant impact on the auditory system, a subset of research has looked specifically at the changes in the auditory system related to PLD uses. In order to evaluate the potential effects of PLD uses on a larger scale, studies using large population samples have evaluated the differences in the auditory system between PLD users and non-users. Research using otoacoustic emissions (OAEs) as biomarkers for cochlear damage due to overuse of PLDs has identified clinically significant differences between PLD users and non-users. LePage and Murray (1998) identified decreased click-evoked OAE levels in some groups of personal stereo users compared to similar, non-exposed peers. In the youngest listener group, age 10-19, no significant differences were noted between PLD exposure groups. In listener groups aged 20-29, 30-39, 40-49 and 50-59, listeners who reported little use of PLDs had significantly higher OAE levels than listeners reporting moderate or heavy PLD uses. The authors suggest that a clear age effect is present in OAE levels for heavy PLD users compared to light users. This age effect implies that cochlear damage occurring due to listening to PLDs may not be seen in teenage years, but is measureable after an extended period of exposure. Similar results were identified by Santaolalla Montoya et al. (2008), who found decreased TEOAE and DPOAE levels in listeners who had used MP3 players for longer periods of time compared to listeners who had not used MP3 players. In this sample, the incidence of decreased OAE levels was higher for listeners who had used MP3 players for longer periods of time and for more hours per week.

Evaluation of hearing thresholds across populations can be used to observe the differences between people exposed to music from PLDs and people who do not use PLDs. Using a large sample, Meyer-Bisch (1996) found increased hearing thresholds in groups that used portable cassette players, groups that attended discotheques, and groups that attended rock concerts when compared to age-matched control groups who did not participate in similar music-listening activities. An effect of duration of use of cassette players was also found, with subjects who used the devices more than seven hours per week incurring worse hearing thresholds than those who listened between two and seven hours per week. In a study with a smaller sample, Vinay and Moore (2010) found significantly worse hearing thresholds above 2,000 Hz in a group of eight men reporting use of PLDs than a similar group of six non-users. The authors also identified that the group of PLD users had significantly higher frequency discrimination thresholds for frequencies at 3,000 to 8,000 Hz than the control group of non-users.

In a study of 490 middle and high school students, Kim and colleagues (2009) identified significant elevations of hearing thresholds at 4 kHz in students who reported PLD use for greater than 5 years, compared to those who reported no PLD use. In addition, a group of students reporting greater than 15 years of PLD use had significantly worse hearing thresholds at

4 kHz than students reporting less than 15 years or PLD use. Furthremore, participants who used speakers with their PLDs had better average hearing thresholds at 4 kHz than participants who used either insert earphones or headphones. A similar study by Peng, Tao and Huang (2007) of 150 university students compared the hearing of a control group of students who had not used PLDs and groups of students reporting 1 to 3, 3 to 5, and greater than 5 years of PLD use. Significantly worse hearing thresholds at 3 through 20 kHz were identified in each of the PLD use groups when compared to the control group. No differences were seen in hearing thresholds between the PLD use groups. Overall, the results of this study are parallel to those found by Kim and colleagues (2009) in younger listeners, and are indicative of widespread effects of PLD use on hearing. However, when viewed in a clinical context, it should be noted that both studies evaluated only participants who reported normal hearing, excluding any participant with diagnosed hearing loss or history of otologic disease. Consistent with the subject selection criteria, both studies showed average hearing thresholds in their samples to be below 20 dB HL, within the clinically normal limits for hearing. However, the significant differences between PLD users and non-users are suggestive of early hearing loss attributable to PLD use.

Using population sampling, several studies have found no differences in hearing thresholds between PLD users and non-users. In a large cohort of 18-year-olds, de Beer, Graamans, Snik, Ingels, and Zielhuis (2003) found no significant relationship between history of of PLD use and hearing thresholds. However, the analysis consisted only of a comparison of the participants with the highest level of PLD usage compared to a group with the lowest PLD usage. It is likely that, at age 18 years, a listener has had a low cumulative exposure to PLD music over the lifespan, and differences may emerge in later years. In a similar cross-sectional study, Shah, Gopal, Reis, and Novak (2009) screened the hearing of PLD users and found no relationship between PLD use and failure rates for the hearing screening. However, the researchers did not measure PLD use, and did not report how they asked listeners to report their PLD usage, only noting that 55% of undergraduates listened at “somewhat loud” or “very loud” level. Additionally, the researchers noted but did not control for several confounding issues, including the high ambient noise in the screening room, the age of the listeners and the presence of cerumen in the ears causing failure of the hearing screening.

In a more controlled study, Kumar, Mathew, Alexander, and Kiran (2009) found no significant differences in hearing thresholds or in DPOAE amplitudes between PLD users who typically were exposed to less than 80 dBA L_{eq} and users exposed to greater than 80 dBA L_{eq}. However, a significant positive correlation was noted between hearing thresholds at 6,000 Hz and music exposure levels, and a significant negative correlation between OAE amplitudes at 6,340 Hz and music exposure levels. The authors suggested that the correlation findings may reflect subtle, pre-clinical damage to the cochlea, and that exposure over time could be hazardous to hearing (Kumar et al., 2009).

Measurement of PLDs: Technical and theoretical issues

It is important to note that several technical and theoretical issues have a significant impact on how PLD use is measured and evaluated, as well as on the accuracy of output level measurements. Understanding these technical issues is a prerequisite for discussing research regarding both output levels of and how individuals use PLDs. At present, two international standards describe methods of measuring the output levels generated by sound sources close to the ear. First, ISO 11901-1 (2002) describes a microphone in real ear (MIRE) technique, in which a miniature microphone or a probe tube is placed in the ear canal. Under this standard, the use of a soft, flexible probe tube allows for measurements to be taken close to the eardrum. Second, initially identified by Rice, Breslin and Roper, (1987), ISO 11904-2 reports on a method of placing the headphones of a PLD onto the ear simulator of an acoustic manikin (ISO, 2004). Both of these techniques have been used in the evaluation of PLD output levels across the literature reported above. When the two methods are directly compared, they result in measurements that are similar, though Worthington et al (2009) reported that the variance of the MIRE technique is lower than that of the manikin technique.

Regardless of which method is used for measuring the output level of a PLD, care must be taken to ensure that the measurements can be compared to both reported measures in the literature and published DRC. Outcomes of measurements must share two important characteristics: they must be A-weighted and must be reported in free-field equivalent values. Each of the published DRC (NOISH, OSHA, European Union, World Health Organization) use A-weighted sound pressure level measurements in their calculations of risk and permissible exposure levels, and failure to use A-weighting means that measured levels cannot be compared to a DRC.

Reporting free-field equivalent output levels is critical for interpreting sound pressure level measurements from a PLD. Each of the DRC assumes industrial noise exposures measured in the free-field. Due to the natural amplification of the ear canal, a sound source measured near the eardrum will have a higher levels in the 2 to 7 kHz range, than if the same source were measured in free-field (Shaw, 1974). Thus, to compare a sound level measured at the eardrum to a DRC, a transfer function designed to subtract the resonance added by the ear canal must be applied to the measurement. Each ISO standard for measuring ear-level sound sources provides a transfer function defined in one-third-octave correction factors for transforming ear-level measurements to free-field equivalent levels; ISO 11904-1 (2002) provides a transfer function for measurement when using a MIRE technique and ISO 11904-2 (2004) provides a transfer function for use with an acoustic manikin. Alternatively, an individual transfer function can be created by measuring the difference between a known free-field sound source and the levels of that source measured at the eardrum. Measuring individual transfer functions reduces measurement uncertainty somewhat when using the MIRE technique, as using correction factors assumes homogeneous ear canal resonance properties across research participants.

Measurement of a listener's chosen listening level (CLL) provides a valuable snapshot of the individual's listening preference in the laboratory environment at the moment of measurement. These measures can be used to observe changes in a listener's CLL in varying degrees of background noise, or to observe choices in a specific environment. These methods, however, do not allow for observation of behavior over an extended period of time, as is needed to determine a listener's exposure over the course of a day or week. To evaluate behavior over time, researchers have historically relied on self-reports of listening time and of CLL, using either a rating scale that is related to a PLD's volume control or qualitative reports of loudness. Self-reported CLLs are useful for estimating real-world PLD usage, as listeners can report both the level at which they typically listen and the duration of their listening. However, the validity of listener's self-reports has not been established, and it is unclear whether self-reported CLLs are similar to actual CLLs.

Several other issues arise when quantifying the effects of music on the auditory system. First, it is well established that permanent hearing threshold shifts due to sound exposure are only observable after a substantial cumulative exposure, typically involving years of exposure. In order to identify permanent threshold shift in an individual or a group, longitudinal studies with many years of follow-up evaluations are necessary (Fligor, 2009). Longitudinal studies of PLD use must differentiate between occupational noise exposure, recreational noise exposure and PLD exposure. Quantifying each of these exposures is difficult using self-report questionnaires, as the industrial DRC use specific exposure levels to determine risk. Furthermore, other identifiers of damage to the auditory system indicate only presence or absence of a biomarker, such as tinnitus or OAEs. Unlike hearing thresholds, these markers have little variability once change in the auditory system has occurred, and they cannot be used to track further change in the auditory system beyond their initial identification.

There is also some concern over the use of occupational DRC to evaluate the risk of recreational NIHL or MIHL. DRC, including both the OSHA and NIOSH formulas, are based on large population studies of workers. The data used for these risk assessments were collected in 13 noise and hearing surveys from 1968 through 1971 known collectively as the Occupational Noise and Hearing Survey (NIOSH, 1998). Several authors have suggested that our current modeling of auditory risk, including DRC, may not be adequate to understand music, which inherently has more spectral, temporal and dynamic fluctuation than industrial noise (Fligor & Cox, 2004; Hodgetts, Rieger, & Szarko, 2007; Turunen-Rise, Flottorp, & Tvete, 1991). Moreover, the industrial DRC were developed based on an 8-hour workday exposure, which is not a standard exposure time for music listeners (Worthington et al., 2009). At present, research to determine the equivalency of music to industrial noise is lacking, and large cross-sectional population surveys of music exposure to determine the population incidence of MIHL are difficult or impossible to complete. The ideal evaluation, longitudinal studies of music exposure and hearing loss, have not been undertaken and may not be practical for current researchers to start (Fligor, 2009).

Sound exposure levels from PLD use

When evaluating exposure due to PLD use, one must consider both the potential for high exposure due to maximum output levels of a PLD, and the actual exposure measured over time. When the output levels of a device exceed the REL for a specified DRC, some concern arises that users could put themselves at risk for hearing loss. A significant body of literature in the 1970s through 1990s identified high output levels from tape players, with maximum output levels ranging from 98 to 114 dBA (Airo, Pekkarinen, & Olkinuora, 1996; Catalano & Levin, 1985; Felchlin, Hohmann, & Matefi, 1998; Katz, Gerstman, Sanderson, & Buchanan, 1982; Wood & Lipscomb, 1972). Similarly, Fligor and Cox (2004) identified maximum output levels of compact disc players between 91 and 121 dBA, with a significant variation in output levels from different styles of headphones. Slightly higher maximum output levels for compact disc players were identified by Loth, Avan, Menguy, and Teyssou (1992), though the sound levels reported were measured in an ear simulator without free-field correction factors. Adding a free-field correction would likely bring those measurements to similar levels as those found by Fligor and Cox (2004).

The current generation of digital PLDs is also capable of producing output levels that could increase the risk for acquiring MIHL if used for extended durations. Portnuff et al (in press) reported that current devices produce maximum levels ranging from 97 to 107 dBA, with average levels at 101.5 dBA for earbud style earphones and 97 dBA for supra-aural style earphones. Significant differences were noted for the output levels of earbud style, isolator style and supra-aural style earphones. Very similar output levels were identified by Keppler and colleagues (2010), who found average maximum output levels of 102.5 dBA for earbud style earphones and 97 dBA for supra-aural style earphones using an iPod Nano. In a larger study of output levels, Keith, Michaud and Chiu (2008) identified that output levels of PLDs could exceed those reported by both Portnuff et al (in press) and Keppler et al (2010) when using some aftermarket earphones. This study found output levels with stock earbuds ranging from 101 dBA to 107 dBA, with maximum possible output levels reaching 120 dBA using a combination of players and higher-output earphones. Though these levels are substantially higher than those identified by other authors, they underscore the presence of increased risk of MIHL for users listening at high levels.

How do listeners use current generation PLDs?

While recognizing that the output levels of current generation PLDs are potentially high enough to cause damage to the auditory system, we must evaluate how listeners use their devices to understand the actual risk for MIHL. Survey-based methods of assessment provide a view into the past behavior or future (intended) behavior of listeners. Listening behavior is a combination of both listening duration and listening level. The first reported evaluation of current generation PLD use was a telephone survey of 1,000 adults and 301 high-school age students that was commissioned by the American Speech-Language Hearing Association (Zogby International, 2006). Fifty-two percent of the adults surveyed reported that a typical listening session lasted between one and four hours or longer than four hours while only 31 percent of teenagers listened to their players for longer than one hour during a typical listening session.

In college students, exposure time is generally reported to average about 2 hours per listening session, though with some variation across the literature. Ahmed, King, Morrish, Zazewska, and Pichora-Fuller (2006) reported that 46 percent of listeners reported using PLDs five to seven days per week for an average of a 2 hour listening session. Five percent of those listeners reported listening 4 to 8 hours per listening session. Torre (2008) reported that 48 percent of users listen between 1 and 3 hours, 12 percent listen between 3 and 5 hours, 4 percent listen for greater than 5 hours and 35 percent listen for less than 1 hour per listening session. In this group, men were significantly more likely to report longer listening times than women. Danhauer and colleagues (2009) reported that 39 percent of users listen for 1 to 2 hours per day and 21 percent of users listen for more than 3 hours per day. Of this group, 54 percent of users listened 5 to 7 days per week. Finding very similar results to Danhauer et al, Hoover and Krishnamurti (2010) reported that 18 percent of college students listen to PLDs for one hour per day, 36 percent listen for 1 to 2 hours, and 21 percent listen for greater than 3 hours per day. In their sample, 54 percent listen 5 to 7 days per week. Across these surveys of students, the majority of listeners use PLDs around 2 hours per day, though a substantial percentage of each sample had longer daily listening times. Considering the high potential output levels reported for digital PLDs, it seems likely that at least some of these young adults would be exceeding a 100 percent noise dose.

Survey methods assessing listeners' CLLs describe a range of levels using several methods of reporting CLL. The ASHA survey used a subjective rating scale from soft to very loud, finding that teenagers were more likely to play their music at a somewhat or very loud setting (59 percent of respondents) compared to adults (34 percent of respondents). Danhauer and colleagues (2009) used a similar loudness rating scale and found that 35 percent of college students listened at "loud" or "very loud" levels. With similar results, Torre (2008) reported that 35 percent of a large sample of university student survey respondents listened at a "loud" level, while 6 percent listened at a "very loud" level. To determine what output levels corresponded to their qualitative loudness assessments, a smaller set of listeners (n=32) was asked to choose listening levels based on the study's descriptors. The CLLs measured using a MIRE technique indicated that a "loud" level corresponded to a mean of 87.7 dBA while "very loud" corresponded to a mean 97.8 dBA CLL. However, both the levels associated with the "very loud" and "loud" descriptors had large standard deviations (5-9 dBA), indicating that the physical levels corresponding to listeners subjective descriptions of loudness vary considerably.

Other surveys have asked people about their typical settings on the volume control of their PLD. The volume control on a PLD is directly related to the output level of a set of earphones, and in general, a 10 percent increase in the volume control is equivalent to a 6 dBA increase in output level (Portnuff et al, in press). As noted earlier, though, significant variability exists depending on the earphones that are used with the player (Keith et al., 2008). Ahmed and colleagues (2006) asked college students to report their preferred setting by a percentage of the volume control. The average setting of this group was 60 percent of the maximum volume, with 14 percent of listeners reporting levels greater than 80 percent of maximum volume. Hoover and Krishnamurti (2010) asked participants to report their preferred volume settings by quartiles of the volume control. About half of the listeners reported using their players above 50 percent of maximum volume, and 23 percent of listeners reported listening between 75 percent and 100 percent of the maximum volume level. Danhauer et al (2009) used a 1 to 10 Likert scale to rate the preferred volume control settings, finding that 21 percent of users listened at a "6" on the scale, 25 percent listened at a "7" and 26 percent listened between "8" and "10". Across all of these surveys, it is clear that a small but substantial group of PLD users choose high CLLs, and at least some of this group could be increasing their risk for acquiring MIHL.

Other studies have attempted to evaluate listeners' CLLs using direct measurement through the manikin or the MIRE technique. Several researchers have used a manikin technique in a naturalistic environment, such as stopping PLD users on the street and taking measurements of their devices. Williams (2005) measured the CLLs of adult PLD users passing through noisy public areas by placing earphones on a manikin and found a mean CLL of 86.1 dBA. When self-reported listening times were taken into account, the mean exposure was 79.8 dB $L_{Aeq,8h}$ and 25 percent of users achieved an estimated exposure greater than 85 dB $L_{Aeq,8h}$. A follow-up study in 2009, using the same methods as the 2005 study, found a significantly lower mean CLL of 81.3 dBA, with 17 percent of listeners exceeding 85 dB $L_{Aeq,8h}$, potentially increasing their risk for MIHL (Williams, 2009). Using similar methodology, though using a recording system instead of a manikin, Epstein, Marozeau and Cleveland (2010) measured the outputs of iPod users in a subway, on a busy street, in a library and in a student center. In contrast with the Williams (2005, 2009) studies, the authors found that out of the 64 users evaluated, none chose levels greater than 85 dBA and that the maximum recorded NIOSH noise dose was 10 percent. Epstein, Marozeau, and Cleveland (2010), then, report no risk for hearing loss in the population that they sampled, including in moderately noisy places.

Several recent studies have used a similar paradigm of manikin measures in a public place to assess sound exposures. Levey, Levey and Fligor (2011) measured the CLLs of people entering an urban university campus in New York City. The researchers found average CLLs of 92.6 dBA, and an average weekly noise dose of 157%. Of this group of listeners, 51.9 percent exceeded a 100 percent weekly NIOSH noise dose from their PLD exposure. Additionally, the study found no differences in CLL between PLD users who were just coming out of the subway and those who were not. Using a similar paradigm, Kahari, Aslund, and Olsson (2011) used a manikin to measure the CLLs of PLD users in the central hall of a train station in Stockholm, Sweden. This study identified an average CLL of 83 dBA (range: 73-102 dBA), and that 46 percent of participants had CLLs exceeding 90 dBA. However, though the authors report average usage times, the data are not transformed into an exposure method that considers both level and duration of exposure. Thus, with this data it is difficult to assess the number of listeners who are risk for MIHL from PLD use.

As the studies of Williams (2005, 2009), Epstein, Marozeau and Cleveland (2010), Levey, Levey and Fligor (2011) and Kahari, Aslund and Olson (2011) are similar in methodology, it is clear that some substantial variability in CLLs are present. The disparities between these results may be reflective of differences between the populations sampled. Certainly, it is possible that population usage patterns could vary geographically; Williams (2005, 2009) took measurements in major cities in Australia, while Epstein, Marozeau and Cleveland (2010) took measurements in Boston, USA and Levey, Levey and Fligor (2011) took measurements in New York City. Moreover, the ambient noise levels in the study environments may have some variability, affecting the CLLs of participants.

Measurements in the laboratory of CLL provide a more controlled view of how listeners use PLDs. Using a MIRE technique in the laboratory, Fligor and Ives (2006) evaluated the CLLs of 100 graduate students ranging in age from 20 to 46 years (mean: 23.8 yrs). In this group, 6% of listeners had CLLs which exceeded 85 dBA in quiet, a level which could increase the subjects' risk for hearing loss. The researchers also measured CLLs in quiet and in several levels of background noise, pink noise from 50-80 dBA, a restaurant background noise and an airplane background noise. A linear relationship between CLLs and the level of background noise was identified for each earphone. The authors reported that listeners chose significantly lower CLLs when the listeners used earphones with high background noise attenuation than when they used earbuds or supra-aural earphones with little background noise attenuation.

Another group of college-age students was evaluated in the laboratory by Hodgetts, Rieger, and Szarko (2007) using a MIRE technique. In this study, listeners had mean CLLs of 76.0 dBA in quiet, 83.7 dBA in a 70 dBA multi-talker babble, and 85.4 dBA in a 70-80 dB street noise. Additionally, listeners chose higher output levels when using earbuds than when using supra-aural style earphones and the authors conclude that supra-aural earphones reduce the risk of MIHL when used in noise. However, as the authors described their supra-aural earphones as a "closed style," it is likely that the supra-aural earphones also provided some passive attenuation of background noise that the earbuds did not. Some of the effect of earphone style may be due to background noise attenuation in the supra-aural style. More importantly, though, the authors presented CLLs as measured by a probe microphone at the eardrum without applying a free-field equivalent transfer function. Thus, the numbers reported cannot be compared directly to either industrial DRC or other studies. A follow-up study by the same authors measured CLLs while exercising and in background noise (Hodgetts, Szarko, & Rieger, 2009). This study found a significant increase in CLL both when exercising and when resting in the presence of background noise. However, similar to the previous study, the CLLs were not reported as free-field equivalent numbers, and thus cannot be compared directly to DRC or to other studies.

Farina (2007) examined the PLDs of 13 Italian high school students, measuring on a manikin the output of their players set to the last level used, and found an average free-field equivalent setting of 85.3 dBA. The author, though, noted that the players measured were all sold on the European market, where PLDs sold have a statutory maximum output of 100 dBA. Kumar and colleagues (2009) measured the CLLs of 70 participants listening to music through primarily mobile phones, using a MIRE technique resulting in free-field equivalent output levels. In quiet and in a 65 dBA background noise, listeners chose an average 73 dBA level, with a range of 40 to 93 dBA. No significant difference was identified between the quiet and 65 dBA conditions. Additionally, the owners of the PLDs were surveyed about their duration of listening, and the researchers reported that 30 percent of the participants would be exposed to 80 dB $L_{Aeq,8h}$ if they used their player for that length of time at their CLL. An examination of the data reported in this study suggests that 14 percent of listeners would be exposed to greater than 85 dB $L_{Aeq,8h}$ each day.

Concerns about measures of listening behavior

Though the majority of the literature suggests that a small percentage of listeners are at risk for MIHL, some concerns exist regarding the measurement techniques commonly used in this domain, in both the laboratory measurements and the survey measurements. Certainly, laboratory measurements of CLL provide a very sensitive measure for understanding listeners' choices; however, the external validity of measurements in the laboratory is sometimes questionable. It is difficult to know if the measurements taken in the laboratory setting are consistent with those that a listener chooses during everyday use of their PLD. Simulated environments in a laboratory may not truly reflect the listener's individual experiences, and listeners may choose different levels when focusing on a CLL task in the laboratory than when listening for pleasure at home. In an attempt to provide a more realistic measurement of PLD use, measurements have been taken in public places using an acoustic manikin (e.g. Williams, 2005, 2009). However, even with measurements in public places, the measurement is a single snapshot of the listener's choices, and may not be representative of CLL in other environments.

PLD users may vary their listening levels as a function of their individual environment. Most importantly, though, is that laboratory measures alone cannot provide an estimate of the listener's overall risk of acquiring MIHL due to PLD use, as these measures do not take duration of PLD use into account.

As subjective measures, survey methods designed to assess the population-level risk to hearing from PLD use also have several inherent limitations. In other domains of health research, self-reports have been used as a validated tool to study obesity, condom use, and vitamin use, among many other topics (Paradis, Pérusse, Godin, & Vohl, 2008; Satia-Abouta et al., 2003; Shew et al., 1997). In the health behavior literature, a variety of cognitive and situational factors may contribute to response bias, in turn affecting the validity of self-report measures (Brener, Billy, & Grady, 2003). Cognitive factors include the ability of the respondent to recall their behavior. Situational factors may include a likelihood of respondents to provide socially acceptable responses in order to improve their standing with the researcher (Aguinis, Pierce, & Quigley, 1993; Crowne & Marlowe, 1964). Reports about seatbelt use, for example, are subject to cognitive factors such as the ability to recall the frequency of seatbelt use, as well as situational factors such as the desirability of being seen as a person who uses a seatbelt (Brener et al., 2003). In this domain, though, the median ratio of reported seatbelt use to observed seatbelt use is 1.05, indicating that self-reports are accurate (Nelson, 1996).

Comparisons of self-report to a monitored behavior provide an excellent system for evaluating the validity of self-reports. In some domains, objective measures of behavior can be considered a "gold standard" for evaluation. For example, self-reported cigarette use can be compared to serum levels of cotinine, a biomarker of nicotine use. Using this technique, Wagenknecht et al (1992) identified that smokers underreport cigarette use significantly.

However, not all objective measures are as accurate a metric as serum levels. Evaluations of physical activity have included the use of bioactivity monitors or accelerometers over time as measures that can be compared to self-reported activity level. Generally, strong correlations have not been seen between self reports and measured activity levels, which may be due to either inaccurate self report or limited measurement capabilities (Brener et al., 2003).

In the nutrition domain, several techniques for monitoring have been used for many years, including both self-report dietary diaries and the use of dietary biomarkers (de Castro, 1988; de Castro & Kreitzman, 1985). Dietary diaries have been noted to be unreliable when relying on recall of foods consumed in the past, but very reliable when motivated subjects record food data at the time of consumption. In addition to providing information, the use dietary diaries may influence typical eating habits (Balogh, Kahn, & Medalie, 1971). The act of completing a dietary diary is a strategy used to change food intake and to affect weight loss (Avenell, Sattar, & Lean, 2006). Nutritional biomarkers, such as serum levels of minerals or vitamins, have also been used to assess the presence of nutrients as a proxy for foods consumed. Brunner et al (2001) used biomarkers to compare a seven day diet diary to a questionnaire asking about frequently consumed food, and found that both performed similarly.

In the field of hearing health, self-reports of hearing aid use are often inaccurate due to both cognitive factors, including an inability to recall usage patterns, and situational factors, including a desire to be seen as a good patient (Humes, Halling, & Coughlin, 1996; Taubman, Palmer, Durrant, & Pratt, 1999). In digital hearing aids, datalogging circuitry has allowed hearing aid providers to monitor the actual usage of a hearing aid. A majority of users overestimate their hearing aid use per day, though there is a moderate correlation between self-reported use and actual use (Gaffney, 2008, June; Mäki-Torkko, Sorri, & Laukli, 2001).

Unfortunately, though, no research to date has evaluated whether the presence of datalogging information changes hearing aid users' behavior. Anecdotally, pediatric audiologists have used datalogging to hold parents of children wearing hearing aids accountable for their child's hearing aid usage patterns with an objective measure of use. The potential exists for using this type of usage verification as a counseling tool to affect behavior change in hearing aid wearers.

To date, no research has established the external validity or accuracy of questions designed to report past PLD listening behavior. Though Torre (2008) attempted to quantify subjective loudness judgments by measuring levels and asking participants to rate the loudness, each loudness category (i.e. "soft" or "loud") had a wide range of associated measurements with high standard deviations. From the data presented in the Torre (2008) study it is difficult to connect a subjective loudness report to a specific output level. These difficulties are certainly reflective of both the complexity of and subjectivity of the construct of loudness (Fletcher & Munson, 1933).

PLD users may also be unaware of the levels at which they have their devices set, leading to inaccurate responses. Similar to some other domains of health research, this cognitive factor requires listeners to have monitored their own behavior in the past and be able to accurately recall that behavior. In addition, even when listeners may recall their average CLL, it is also possible that a uni-dimensional metric of CLL may not capture the varied range of volumes a listener may set while listening to a PLD. Though little research has specifically evaluated volume variation, anecdotal evidence suggests that volume settings may change as a result of background noise, music preference, or activities being performed while listening. In summary, no research has examined whether self-reported listening behavior accurately reflects actual behavior. Whether due to situational factors affecting the desire of the respondent to report accurately, or due to cognitive factors that limit the ability of the respondent to report accurately, the accuracy of self-reported listening behavior is questionable.

Individual factors that may influence listening behavior

With the acknowledgement that at least a small group of adolescents and young adults are putting themselves at risk for MIHL due to their PLD use patterns, the immediate concern for intervention is to determine why this group engages in risky behavior. Certainly, more knowledge about this group would be useful in order to create interventions. To date, little research has focused on understanding the differences between listeners who are at risk for MIHL and listeners who are not at risk. For large scale educational interventions, demographic details of these groups could provide some useful information. Indeed, some research has suggested that certain groups may choose higher PLD listening levels than others. Age, for example, has been suggested anecdotally as a factor that may affect listening levels. Limited research has supported this claim, showing that older teenagers choose higher levels than younger teenagers, though this finding has not been replicated in users of digital PLDs (Ising, Hanel, Pilgramm, Babisch, & Lindthammer, 1994; Maassen et al., 2001). Mixed results have been found looking at gender differences where several studies have found that males have higher overall calculated exposure than females (Fligor & Ives, 2006; Hanel, 1996; Mercier & Hohmann, 2002; Meyer-Bisch, 1996; Williams, 2005, 2009). In a survey, Torre (2008) identified that men were significantly more likely than women to report higher using PLDs at "very loud" levels and were more likely than women to report longer listening durations. Other studies found some divided results, where males chose higher levels in quiet, but no differences were present in background noise (Fligor & Ives, 2006; Worthington et al., 2009). In contrast, similar studies found no significant differences in CLL between males and females and many others did not report statistical results regarding gender (Kumar et al., 2009). To date, though, few studies have used large-scale, validated measures to compare the CLLs of various demographic groups. More research is needed to assess whether there is any true difference in CLL related to gender or age.

Attitudes toward noise and music. Individual attitudes towards noise and noise-induced hearing loss may have an effect on the levels that listeners choose for their PLDs. In order to investigate attitudes regarding noise, Widén and Erlandsson (2004) created the Youth Attitudes towards Noise Survey (YANS). The YANS evaluates four constructs: attitudes towards noise associated with youth culture, attitudes towards daily noises, ability to concentrate in noisy environments, and an individual's intent to influence their sound environment. An evaluation of Swedish adolescents indicated that socioeconomic status (SES) is associated with individual attitudes towards noise and that teenagers coming from lower SES backgrounds generally had more positive attitudes toward noise and were less likely to wear hearing protectors in noisy environments (Widén & Erlandsson, 2004). In a comparison between college students in the U.S. and Sweden, American males generally had a more positive attitude towards noise than Swedish males, and in both countries, males were more likely to have positive attitudes towards noise than women (Widén, Holmes, & Erlandsson, 2006). Moreover, individuals with a negative attitude towards noise were 8.8 times more likely to wear hearing protectors at concerts than those with negative attitudes and individuals worried about hearing loss were 4 times more likely to use hearing protectors in a concert setting. Additionally, Swedish students were 12.7 times more likely than American students to use earplugs at concerts. However, this disparity may be mediated by the availability of hearing protectors; In Sweden, earplugs are required to be provided at loud concert venues, but in America they are rarely available at concerts (Widén et al., 2006).

In another survey of American college students, Widén, Holmes, Johnson, Bohlin, and Erlandsson (2009) combined the YANS with a survey of auditory symptoms and hearing protector use. Within this group, 26 percent failed a hearing screening at 20 dB HL (500 Hz to 6000 Hz), but only 4 percent of the group reported existing permanent hearing loss in the auditory symptom questionnaire. When compared to the results of the YANS, individuals reporting no hearing symptoms had more positive attitudes towards noise than those who had self-reported hearing symptoms, regardless of whether or not they passed the hearing screening. Overall, self-experienced symptoms, including hearing loss, were more strongly related to anti-noise attitudes than hearing loss alone. The authors suggested that a self-experienced symptom could serve as a trigger for later health preventative behaviors (Widén et al., 2009), and noted that this is consistent with Widén's (2006) theory that self-experience may change an individual's self-perception of vulnerability to consequences of a risk-taking behavior. This theory explains the results of a survey by Bogoch, House and Kudla (2005), which showed that concert patrons who reported experiencing hearing loss were 3.2 times more likely to wear hearing protection than those who had not experienced hearing loss. Similarly, Rawool and Colligon-Wayne (2008) found a significant association between the use of hearing protection during occupational noise exposure and experience with hearing loss in college students.

Specific attitudes regarding PLD use have been evaluated by several researchers. Danhauer and colleagues (2009) identified that, though 71 percent of users reported listening at 60 percent of the maximum volume on a PLD, most listeners considered this a "medium" volume. In their survey group, they also identified that 7 percent of listeners experienced tinnitus “sometimes” following use of an iPod, and 13 percent of listeners experienced hearing loss “sometimes” following use of an iPod. Of this group, 86 percent agreed that the use of an iPod at loud levels could damage hearing, and 54 percent agreed that iPods should include warning labels about hearing loss. However, 61 percent of the college students did not desire to have more information about iPod use and potential hearing loss. In a similar survey, Hoover and Krishnamurti (2010) found comparable levels of concern about hearing loss and that about 50 percent of listeners would be willing to either decrease the volume or reduce exposure time in order to protect their hearing. Additionally, this survey identified some safety concerns, as listeners reported decreased environmental awareness when using PLDs (Hoover & Krishnamurti, 2010).

Overall, several trends appear in the limited research looking at adolescent attitudes toward PLD use. First, there seems to be a relatively high number of students who report understanding that high levels of sound can cause hearing loss, and that PLDs are capable of producing that type of output. Young adults tend to perceive hearing loss as a significant problem, though the level of concern about MIHL tends to be somewhat lower. Furthermore, several studies have suggested that teenagers and young adults may have a sense of invulnerability to hearing loss. In a series of structured interviews, Vogel, Brug, Hosli, van der Ploeg, and Raat (2008) asked adolescents about their PLD use and found that the teenagers underestimated their risk and vulnerability to MIHL. Moreover, though the teenagers reported that problems related to hearing loss would be severe, few reported regular concern about MIHL due to their own use patterns. The lack of concern for MIHL in students who had not experienced symptoms of hearing loss is consistent with Widén’s (2006) theory that a sense of vulnerability comes from experience. However, some interviewees who reported having experienced temporary symptoms, such as tinnitus, assumed that the symptoms were always temporary, rather than an indicator of ongoing damage to the auditory system, or as a warning sign. The lack of concern in this subgroup may suggest that an individual's change in mindset towards vulnerability requires a more permanent impact from PLD use to trigger a feeling of vulnerability.

In concert with these theoretical bases for experience mediating behavior, Widén and Erlandsson (2007) interviewed a set of young adults to assess how risk perception, self-image and socially normative behavior influenced the perception of music as a means to create identity. The authors suggested that, as reported earlier, individuals who perceive a significant impairment from listening to loud music perceive themselves as vulnerable and are more likely to take preventative actions. Similarly, the interviewees who reported that they consider the risk of exposure to loud sound were more likely to demonstrate an external locus of control and to affect changes to their environment via hearing protection or behavior modification. However, social normative behaviors mediated the actions taken to reduce risk. The interviewees reported that, when hearing protection use is not an acceptable norm, they were much less likely to use it. Similarly, individuals stated that they were likely to follow the example of a social group instead of taking preventative behavior, such as attending a loud concert to noisy disco. The authors proposed that the impact of socially normative behavior on taking preventive actions must be considered in any intervention or model of behavior (Widén & Erlandsson, 2007).

Sensation-seeking and risk judgment. The CLLs of PLD users may also be reflective of the individual's personality, with specific focus on risk-taking and sensation-seeking preferences. Sensation-seeking has been identified as a personality trait defined by the seeking of varied, novel, complex and intense sensations and experiences and the willingness to take risks for the sake of having these experiences (Zuckerman, Eysenck, & Eysenck, 1978). The theory of sensation-seeking consists of four dimensions: thrill and adventure seeking, novel experience seeking, disinhibition through interpersonal contact, and boredom susceptibility. The act of listening to loud music at the risk of MIHL can be considered a sensation-seeking behavior (Rawool & Colligon-Wayne, 2008). The Arnett Inventory of Sensation Seeking makes the assumption that listening to loud music is a sensation seeking behavior and includes a question about preferring music to be loud (Arnett, 1994). An off-shoot of sensation-seeking, the personality trait of risk-taking is also associated with a preference for loud sound. Adolescents who listen to heavy metal music have been identified to score higher on the sensation-seeking inventory, as well as in an inventory of reckless behavior (Arnett, 1990). Bohlin and Erlandsson (2007) combined the Adolescent Risk-Taking Questionnaire (ARQ) with the YANS and a survey of symptoms of auditory effects of noise. The ARQ measures risk judgments and risk behaviors by assessing how often the subject participates in a set of risky activities (Gullone, Moore, Moss, & Boyd, 2000). Bohlin and Erlandsson (2007) identified a correlation between generalized risk-taking behavior and risky behaviors related to loud noise, such as attending concerts and discos. Additionally, within the adolescents studied, women were more likely than men to judge noisy situations as risky. Though not yet studied systematically, it seems likely that CLLs for PLD use would be related to an individual's sensation-seeking or risk-taking attributes.

Psychological aspects of music. A wide variety of theoretical bases for the appeal of loud music have been presented from a large set of sources. Certainly, as a function of youth culture the loudness of music functions as a way to express deviance and separation from an older generation (Dotter, 1994). Anecdotally, adolescents and young adults have a higher tolerance for and enjoyment of music played at a high volume than children and older adults, and loud music can be a defining characteristic for the identity of “youth” (Weinstein, 1994). Music is a powerful stimulus for altering mood, and can even be used as treatment for auditory hallucinations (Bruner, 1990; Johnston, Gallagher, McMahon, & King, 2002). For the listener, a PLD can be used to drown out the external noise and allow for the exertion of control over the individual’s auditory environment. In the urban environment, PLD use allows for the individual to shape their experiences through music (Simun, 2009). Hétu and Fortin (1995) describe the experience of listening to amplified music in a discotheque as an immersion in a shared musical sound field. In the discotheque, music is a type of “mechano-acoustic arouser” that is energizing to young people. As disco music tends to have more salient low frequencies with rapid rhythm, the pulsation of music is perceived by the auditory and proprioceptive systems as acoustic and vibratory sensations (Hétu & Fortin, 1995). As the vestibular system is sensitive to loud auditory input, as seen in the vestibular evoked myogenic response, loud music may stimulate a pleasurable sensation from the saccule (Todd & Cody, 2000). Furthermore, movement can influence the auditory system’s perception of meter and rhythm, which may be mediated by the vestibular system (Phillips-Silver & Trainor, 2008).

Loud music has also been recognized as having similar properties to addictive substances, such as drugs and alcohol. Certainly, loud music has commonalities with the major properties of addictive substances described by Donovan (1988): capacity to induce rapid changes in mood and level of arousal, ability to reduce negative states, and ability to induce the experience of craving. Adorno (1976) describes an addiction to the distraction provided by music that comes from constant listening, a feeling reported by the PLD users interviewed by Simun (2009). One PLD user describes her devices as “like a psychotropic drug” and describes cravings occurring when she did not have her device for an extended period of time (Simun, 2009). To examine music listening as an addictive behavior, Florentine and colleagues (1998) adapted a validated alcoholism screening test to develop the Northeastern Excessive Music Listening Survey (NEMLS). Across the 90 participants who completed the survey, eight scored in a range suggestive of maladaptive behavior. To date, no other research has examined the NEMLS, though this pilot study reported a strong overall validity for the NEMLS.

When framed as an addictive behavior, listening to loud music can also be looked at as a psychological trade-off between the negative effects and the positive rewards on the body and mind. The negative consequences, both physical and perceived, have been described earlier in this paper. Blesser and Salter (2008) provide a structure for understanding these rewards, framing the rewards within the categories of “altered states of consciousness” and “controlling the experience of social space.” The authors propose that listeners’ emotional responses to music can be mediated and amplified by loudness, suggesting that loudness represents a psychological construct of power and machismo, and that higher levels tend to intensify the enjoyment of music. An alteration of the listener’s state of consciousness is achieved by enhanced sensory input, fulfilling need for sensation-seeking behavior (Zuckerman et al., 1978). The authors also consider the concept of soundscapes or aural space as an integral part of the perceived environment, and identify that music can change a perception of space by masking environmental sounds. A loud music environment, then, changes the dominant auditory characteristics of the sound space, altering a person’s perception of that space focus on the music rather than the venue. Blesser and Salter (2008) propose that an acknowledgement of both the risks and rewards of loudness is important when addressing the concerns of hearing loss with individuals at risk for MIHL.

Listening Habits Questionnaire development

In initial research for this project, Portnuff et al (in press) used behavioral measures of CLL, survey measures of CLL and the Listening Habits Questionnaire (LHQ) to study how adolescent attitudes and beliefs influence listening behavior using digital PLDs. To evaluate CLL, the authors used a MIRE technique following ISO 11904-1 (2002), asking listeners aged 13-17 to choose their listening level in quiet, in the presence of 50, 60, 70, or 80 dBA pink noise, in 70 dBA bus noise and 75 dBA airplane cabin noise. Similar to the results of Fligor and Ives (2006), adolescents showed increasing CLLs as the background noise increased. Listeners using earphones that provided sound isolation were more likely to choose levels that were below 85 dBA, especially when the background noise was high. However, the graduate students in Fligor and Ives (2006) had average CLLs using stock earphones ranging from 62.2 to 80.8 dBA in the quiet through 80 dBA conditions, while the adolescents of Portnuff et al (in press) found a range of average CLLs 70.1 to 86.0 dBA for the same conditions. A comparison of the reported CLLs indicates that the teenagers chose levels, on average, 7.5 dB higher than those of the graduate students of Fligor and Ives (2006). This increase in CLLs for adolescents compared to young adults is consistent with the research examining cassette players (Ising et al., 1994; Maassen et al., 2001).

This study also used a survey, the LHQ, for assessing PLD use to determine listeners CLLs over time. Similar to previous research, the adolescents surveyed used their PLDs on average for two hours per day. As a part of the LHQ, the teenagers were also asked to report their typical listening level using a 1-10 scale as an analogue to a PLD volume control. Using output level data for the PLDs, these volume control levels were transformed into CLLs on a decibel scale. This calculation estimated a mean volume control equivalent CLL of 74.1 dBA

(*SD* = 10.8 dBA, range: 52.3 dBA - 91.8 dBA), with twenty percent of participants reporting CLLs greater than 85 dBA. When combined with individual listening times, 14 percent of listeners exceeded 50% of the daily noise dose using NIOSH DRC.

A significant limitation of this study comes in interpreting the CLLs obtained by survey compared to the CLLs obtained by laboratory-based measures. Significant correlations ($p < .01$) were identified between the survey-based CLLs and laboratory-measured CLLs obtained in quiet and in 50 dBA of pink noise. Slightly less significant correlations ($p < .05$) were identified between the survey-based CLLs and the laboratory-measured CLLs in the 60 and 70 dBA of pink noise, 70 dBA bus noise and 75 dBA airplane noise conditions. As significant correlations were identified in multiple conditions, it is difficult to make an assessment that a CLL measured in single noise condition in the laboratory will be similar to the self-report typical CLL. Several possible explanations for the discrepancy between measured CLL and self-reported CLL exist. First, it is possible that self-report of behavior over time is not reflecting the same underlying construct as a behavior in the laboratory. Whereas measured CLLs can be viewed as a psychoacoustic metric, self-reported CLLs reflect a person's perception of their behavior. Similarly, self-reported behavior includes a temporal issue as well; questions asking about past behavior reflect a cumulative report of past activities, while in-lab measures reflect present behavior. Second, the questions that were used to identify past behavior have not been externally validated. At present, it is unclear how accurate listeners are at reporting their past listening behavior. As PLDs have variable volume controls, PLD users may not be aware of how they change their volume levels over time. Considering that PLD users choose higher levels in the presence of background noise in the lab, it seems likely that users would change their volume settings when entering changing levels of background noise in their daily environments. Thus, it is unclear whether a single dimension question (e.g. how loud do you listen?) will capture the variability of daily listening habits. To date, no research has verified the accuracy of listeners' self-reports of CLL.

Portnuff et al (in press) also developed a section of the LHQ designed to assess attitudes and beliefs regarding PLD use and how those beliefs relate to behaviors. This section of the LHQ was designed based on the Health Belief Model (HBM; Rosenstock, 1960). Created in the 1950s to explain risk behaviors and the failure of people to decrease their own risk behaviors, the HBM has been applied to a wide variety of health behaviors (Hochbaum, 1958; Janz, Champion, & Strecher, 2002; Rosenstock, 1960). The components of the HBM are based on the theory that people will take actions to change health behaviors if they feel susceptible to a condition with consequences they feel are serious, and will take actions if benefits of taking action will outweigh the barriers to taking action (Janz et al., 2002). The constructs measured in the traditional HBM include the following: perceived susceptibility, perceived severity, perceived benefits, and perceived barriers. For behaviors requiring lifestyle changes, a construct of perceived self-efficacy to take action can also be included in the HBM (Rosenstock, Strecher, & Becker, 1988). The use of the HBM has been validated in several areas of health behaviors, including nutrition education, mediation compliance and beliefs about hearing loss (Abood, Black, & Feral, 2003; Becker, Drachman, & Kirscht, 1974; Rawool & Colligon-Wayne, 2008). The HBM has been identified as particularly effective in explaining preventative health behaviors, and is widely used to explain health risk behaviors (Janz & Becker, 1984; Rutter & Quine, 2002).

The HBM provides a path model relating the individual constructs within a cohesive system. Rosenstock (1974) argues that the level of an individual's readiness provides the energy or force to act and the perceptions of benefits, minus barriers, provides a preferred path of action. However, he suggests that the combination of these factors could reach considerable levels of intensity without resulting in overt action, unless some instigating event occurs to set the process in motion or triggers action in an individual who is, psychologically, ready to act. Thus, an additional construct of a cue to action has been described as a necessary trigger to taking preventative behaviors. Cues to action have been described as individual experiences that change a person's risk perception, such as falling ill due to poor health or having an accident (Rosenstock, 1966). Adverse effects from exposure to high sound levels, such as tinnitus or hearing loss, could be considered cues to action, and the HBM would predict that these individuals would be more likely to take preventative action. Moreover, individual experiences of adverse effects would likely alter the perceived severity of noise exposure and perceived susceptibility to those auditory effects. The HBM's construct of perceived susceptibility is a core feature of Widén's (2006) theory that self-image guides risk perception, which is a key feature of individual's risk-taking behavior. Moreover, the concept within the HBM that a cue to action is necessary for attitude change underlies Widen and colleagues (2009) contention that a personal experience will trigger behavioral change.

Models such as the HBM provide a framework for evaluating behavior as a function of attitudes and beliefs. Unfortunately, few studies in the field of hearing conservation have used these models to evaluate the factors predictive of health behaviors. Several studies have developed novel survey measures loosely based on the HBM, designed to assess young adults' perception of NIHL and taking of preventive action. However, none have applied the HBM as a complete model to examine the relationship between attitudes and behavior, choosing only to report descriptive data (Crandell, Mills, & Gauthier, 2004; Rawool & Colligon-Wayne, 2008).

Further, other research has looked at attitudinal correlates of adolescents' listening behavior, though without using structured, validated models of health behavior (Vogel, Brug, van der Ploeg, & Raar, 2007). Cognitive theories of health models suggest that adolescents' risk perception and knowledge impact their choices in health behaviors (Greening, Stoppelbein, Chandler, & Elkin, 2005; Reyna & Farley, 2006). The action of "choosing moderate listening levels" is, in itself, a preventative health action. As the HBM has been validated for explaining preventative behaviors, it has been suggested as a good model for understanding knowledge, beliefs and attitudes toward PLD use (Sobel & Meikle, 2008).

To evaluate the use of the constructs of the HBM as predictors of CLL, Portnuff et al (in press) incorporated the HBM constructs into the LHQ. The questionnaire included a total of 26 questions, each designed to represent a part of an HBM construct. The questions were based on a Likert scale with a range of one to seven, with high numbers indicating agreement with the statement. The questions for each construct were averaged into a subscale. Four questions were used to determine an individual's perceived susceptibility to MIHL. These questions asked if participants felt susceptible to MIHL both in general and specifically from using PLDs. Six questions evaluated the individual's beliefs about the severity of MIHL, asking if participants felt that MIHL would be disruptive to their lives and if MIHL was a significant concern for them. Seven questions explored participants' beliefs about the benefits of preventing MIHL. These questions examined the extent to which participants believed that they should take action to prevent MIHL. Four questions were used to assess listeners' beliefs about personal barriers to preventing MIHL. These questions evaluated whether listeners believed that several external factors would impede their ability to prevent MIHL. Five questions addressed participants' beliefs about their self-efficacy for preventing MIHL, determining whether participants felt capable of taking action to prevent MIHL due to PLD use. Looking at the results of the LHQ, the survey showed strong internal consistency and reliability.

A regression analysis of the LHQ results found that the HBM constructs explained 67 percent of the variance of the participants' self-reported CLLs. However, the LHQ was not as good at predicting the laboratory measures, explaining a maximum of 30 percent of the variance for the CLLs measured in quiet and 50 dBA of pink noise, and less for the greater levels of background noise. The self-efficacy construct did not provide a significant increase in explanatory power when added into the model. While these results are consistent with the correlations between the behavior measures of CLL and self-reported CLL, it is notable that attitudes and beliefs are not good predictors of laboratory performance. A closer look at the regression model shows positive regression coefficients for each of the HBM constructs, except for perceived benefits of taking preventative action. This model suggests that increased perceived severity of hearing loss, perceived susceptibility to hearing loss and perceived barriers to preventative action would lead to increased CLLs. Only an increase in perceived benefits of preventing hearing loss would lead to decreased CLLs. However, the interpretation of this regression model is limited by the small subject pool.

Further research needs to examine the external validity of the self-reported CLL, in order to assess whether participants reports are valid. If participants' self-reported CLLs are indeed accurate, the LHQ could be used as a standalone research tool to understand how attitudes and beliefs affect behavior. With a validated LHQ, in order to evaluate these relationships properly, a large number of participants would be needed in order to have enough statistical power to complete path analysis or structural equation modeling. Proper multivariate statistical techniques, such as structural equation modeling, could provide a strong model for how beliefs and behavior interact. Further, an externally validated LHQ could also be used as a measure to monitor attitudes, beliefs and behaviors in the presence of interventions or educational programs designed to reduce CLLs.

CHAPTER 3: STATEMENT OF PURPOSE

In the study by Portnuff et al (in press), interpretation of the LHQ results was limited by two sets of findings. First, behavioral measures of CLL in the laboratory were only moderately related to the self-reported CLL, with the best relationships found in the quiet condition. Second, the HBM constructs of the LHQ predicted self-reported behavior substantially better than they predicted behavior measured in the laboratory. These weak relationships and wide range in the ability of the LHQ to predict behavior may be due to two reasons:

1. Self-report and laboratory measurements are measuring different constructs. Laboratory measures represent snapshots of behavior in a simulated environment, which may not be reflective of the individual's actual listening environment. Self-report measures may better represent real-world behavior over time.
2. Self-report measures and/or laboratory measures are not accurately reflecting actual behavior. The poor fit of the regression model for laboratory measures suggests that the self-report may be measuring perceived behavior, rather than actual behavior. Self-reported listening levels may thus be inaccurate reports of the individual's actual listening behavior.

The overall aim of this research is to help to understand how attitudes and beliefs about hearing loss and the use of PLDs influence listening behavior, and to develop the LHQ as research tool to be used in this aim. Toward that goal, this study has four specific aims:

Specific Aim 1

Characterize and describe the listening habits of young adults through the use of self-reports, laboratory measures, and monitoring listening levels over time.

Research Question 1. What are the usage patterns of PLD listeners, as measured by self-reports of listening habits, laboratory measures of PLD use in background noise, and direct monitoring of listening behavior over time?

In order to assess this research question, a novel system was developed to monitor individuals' listening behavior over time. A group of PLD users had their behavior monitored over time, and then completed a new section of the LHQ with a more detailed self-report of their listening habits.

Predictions. Consistent with previous research, laboratory measures of CLL will increase as a function of background noise, but will show wide ranges and standard deviations. When measured over time, the monitored PLD users are expected to have similar exposure levels to those measured by Williams (2005), though likely less than those found by Levey, Levey and Fligor (2011). For both self-reported exposure and the monitored exposure, a small but substantial percentage of listeners will exceed a 100 percent weekly noise dose.

Implications. The descriptive data evaluating listening habits of PLD users measured here will provide a useful metric for understanding the number of young adults that are putting themselves at risk for MIHL due to overexposure to PLDs. The addition of the monitoring paradigm will allow for a more accurate assessment of risk than have been previously reported using self-reports or individual measurements.

Specific Aim 2:

In order to address the concerns raised by the initial research, this study aims to improve the reporting of PLD use behavior by characterizing and describing how self-reported listening behavior is related to actual listening behavior. Knowing the accuracy of the self-reported behavior metric used in the LHQ will help to clarify what behavioral constructs are ultimately being measured.

Research Question 2. What are the relationships between CLL measured in the laboratory, self-reported listening levels, and actual listening levels measured over time?

Predictions. Self-reported listening levels are predicted to be good rough estimates of overall listening levels, though it is likely that a multi-dimensional question asking listeners to calculate how long they listen at a range of volume control settings will be the best predictor of actual listening levels. Laboratory measurements of CLL are predicted to be only weakly related to actual listening levels recorded over time. Additionally, laboratory measurements of CLL are likely to be poorly related to self-reported listening levels, consistent with past literature.

Implications. The relationships of laboratory-based measures and self-report measures to actual, real-world measurements could have significant implications for interpreting the current body of literature regarding use of PLDs and the potential for hearing loss. If it is found that self-reported levels are not accurate representations of real-world behavior, the validity of literature relying on self-reports may be questionable. However, if some or all self-report questions are found to accurately represent real-world behavior as predicted, these questions may be identified as useful research tools for assessing behavior in PLD users.

Specific Aim 3

Understand the effects of directly monitoring behavior on how the PLD user perceives their listening behavior.

Research Question 3. Does direct monitoring of listening behavior influence a listener's self-report of their listening behavior?

Predictions. The self-reported listening behavior will not change as a result of direct monitoring over time.

Implications. If monitoring listening levels causes a change in a listener's perception of their own behavior, monitoring could be used as an educational tool for intervention.

Specific Aim 4

Establish the relationships between attitudes and beliefs about use of PLDs and hearing loss and listening behavior using the HBM, implemented through the LHQ.

Research Question 4. How do attitudes and beliefs about hearing loss and PLD use relate to both self-reported listening levels and listening levels measured over time?

Predictions. The attitudinal constructs of the LHQ will predict both a multi-dimensional self-report measure and measured behavior well. Additionally, the LHQ will show strong internal consistency and reliability, consistent with the prior research.

Implications. The question or questions that best reflect actual behavior could be used as the primary assessment of listening behavior in the LHQ and could be used in the future to model behavior in a larger population group. Larger sample studies could identify specific areas of attitudes and beliefs in order to create targeted interventions designed to reduce the risk of MIHL due to overuse of PLDs.

CHAPTER 4: METHODS

Participants

A group of young adults was recruited from the Denver and Boulder, Colorado metropolitan area using a combination of advertisements posted online on Craigslist.com and in public areas on flyers. To be eligible for this study, participants were required to report at least 10 hours of PLD use in a typical week using an earbud-style earphone and to deny any symptoms or history of otologic disease or hearing loss A total of 52 subjects were recruited, consisting of 31 females and 21 males between the ages of 18 and 29 years (mean: 25.0 years, median: 25.5 years). For some analyses involving earphone datalogging, the subjects were randomly assigned to either the control or experiment groups. Four subjects who were originally assigned to the experiment group experienced failures of the datalogging device, and were removed from analysis, leaving a total of 48 subjects for analysis. The data for these subjects were evaluated for any analyses looking at survey or laboratory data, but omitted from evaluation for subjects using or not using the datalogging device (experiment vs. control group). The control group consisted of 13 females and 11 males, with a mean age of 25.6 years (range: 18-29 years). The experimental group consisted of 14 females and 10 males, with a mean age of 24.4 years (range: 19-29 years).

Earphone datalogging system

In order to record the real-world use of a PLD, an earphone datalogging system was developed for this experiment. The datalogging system is comprised of a set of earbud-style earphones with a frequency response that had been previously measured. An analog signal splitter is plugged in to the listener's personal PLD, with one end going to the earphones and the other going in to an Etymotic Research ER-200D dosimeter. The ER-200D device has an input jack that provides a calibrated voltage logging system. The voltage logging system can record for up to seven days, recording an A-weighted equalized average of the input voltage for every 3.75 minute interval.

Calibration of the ER-200D. The ER-200D has a calibrated input that is referenced at 94 dB SPL to a 10 mV 1000 Hz test signal. In order to calibrate the output of the ER-200D for each individual earphone, a 10 mV 1000 Hz tone is played through each earphone, and the output is measured in the participant's ear canal using an Etymotic Research ER-7c probe microphone recording into a custom-designed Matlab (The Mathworks) routine. For the probe microphone recordings, consistent with ISO 11904-1 (2002), the microphone is placed into the ear canal and secured to the ear. Otoscopy is then performed by the experimenter to ensure the silicone tubing is within five millimeters of the eardrum. The difference between the recorded level of the 1000 Hz tone in the ear canal and 94 dB can then be used as a correction factor for the specific set of earphones. A second signal, a 10mV broadband noise stimulus, is similarly recorded in the ear canal and the analyzed to obtain a periodogram (power spectrum density function). The periodogram of the noise is then transformed into a filter that represents the individual's ear canal transfer function. The overall gain of this filter can be used as a correction factor for the individual's ear canal resonance. A combination of both the ear canal correction factor and the earphone correction factor provides an overall calibration correction factor that can be applied to the data from the ER-200D dosimeter. The data output of the ER-200D is reported as a single, overall equalized level (L_{eq}) for each averaged 220ms period, summed and stored for every 3.75 minute time period. Addition of the overall calibration factor to the output data will result in free-field equivalent, A-weighted L_{eq} levels. A step-by-step method for this calibration routine can be found in Appendix 3.

CLL evaluation procedure

In order to assess listeners' CLLs as a function of background noise, participants were asked to choose one song from a laboratory iPod that was representative of the music genre they prefer to listen to. Consistent with ISO 11904-1 (2002), a probe microphone (Etymotic Research ER-7c, Elk Grove Village, IL) was placed into the ear canal and secured to the ear. Otoscopy was performed to ensure the silicone tubing was within five millimeters of the eardrum. The individual listener's TFOE was then measured using a broadband noise stimulus presented from the earphone. The listener then set his or her chosen song on repeat, starting with the volume control set to zero, and was instructed to "turn the volume up to the level you like" once the listening trial started. The display of the iPod was obscured from view of the participant. During each listening trial, a 30-second recording was taken using a custom Matlab recording routine, and RMS average levels were calculated with both A-weighting and corrected to free-field equivalent output levels using the individual's TFOE. This measurement procedure was completed in the quiet, and in four background noise conditions: 50, 60, 70 and 80 dB of pink noise. The background noise was presented from two speakers placed at 90 and 270 degree azimuth, each one meter from the listener's ear. Each measurement was repeated three times to assess the reliability of the measure.

Additions to the LHQ

A PLD use questionnaire has been developed to assess how participants are using their PLDs during a typical week, and added to the LHQ as Part 1 (see Appendix 1 for the full questionnaire). The questions of the LHQ that previously assessed listening behavior have been omitted. The rest of the existing LHQ, which consists of questions designed to assess the HBM constructs of perceived susceptibility, perceived severity, perceived benefits to taking preventative action, and perceived barriers to taking preventative action are included as Part 2.

Part 1 of the LHQ consists of fourteen questions about the respondent's use of PLDs, including questions asking about overall duration of use of PLDs in a week, type of PLD used, where the user typically used their PLD, and the type of earphones they used. In order to obtain information about listeners' CLLs, several types of questions will be asked about typical PLD use. The first question asks listeners to report their typical volume control level on a visual-analogue scale from 1 to 10, with 1 representing minimum volume and 10 representing maximum volume of the player. The second question asks listeners to report the percentage of time that they listened at subjective loudness levels from very soft to very loud. The third question asks the duration of time that the respondent used their player at 10 different settings the volume control, represented by deciles of volume control level from 10% of maximum volume to 100% of maximum volume. Participants completed the LHQ questionnaire using a pen and paper in the laboratory setting. A modified version of Part 1 of the LHQ was also created. This iteration included a variation on the wording of each question to reference only the past week's behavior, rather than asking about typical behavior.

Experimental protocol

All experimental visits were completed either in the Hearing Research Laboratory at the University of Colorado in Boulder, CO or at an otolaryngology/audiology practice in Denver, CO (ENT of Denver). The schedule of visits is presented in Table 1. At the initial visit, all participants provided informed consent under a protocol approved by the Institutional Review Board at the University of Colorado. Participants were informed about the study, but were not told whether they were in the experiment group or the control group at that time. A hearing evaluation was completed by the experimenter, a licensed audiologist, for each participant using standard clinical protocols. All participants had hearing thresholds at 20 dB HL or better in both ears at octave frequencies from 250-8000 Hz and at intraoctave frequencies 3000 and 6000 Hz. The hearing evaluation and all subsequent measurements were completed in a sound-attenuating booth complying with ANSI S3.1-1999 standards for audiometric testing. All participants then completed Part 1 and Part 2 of the LHQ. Next, all participants completed the CLL evaluation procedure. Finally, participants who had been chosen for the experiment group were fit with the complete datalogging system using the laboratory earphones. The datalogging system was configured to run for a full week with the power button on the system disabled. The listeners were instructed to use the datalogging system any time that they used their PLD and asked to return in one week.

At the second visit, occurring one week after the initial visit, all participants completed the altered form of Part 1 of LHQ, modified so that all questions referenced only the participant's experiences over the past week. For the experiment group, the data were downloaded from the datalogging system. At the end of the study, participants were offered a debriefing regarding their music exposure. Participants accepting the debriefing were counseled by the experimenter, regarding safe listening levels and their individual risks of hearing loss due to PLD use. All participants were compensated for each study visit and participants in the experiment group were compensated for each day that they used the datalogging system.

Group	Visit 1	Visit 2 (7 days following Visit 1)
Control (20 subjects)	Consent forms Audiometry LHQ Part 1: PLD use LHQ Part 2: Existing LHQ CLL Evaluation	LHQ Part 1: PLD use (modified)
Experimental (20 subjects)	Consent forms Audiometry LHQ Part 1: PLD use LHQ Part 2: Existing LHQ CLL Evaluation Dosimeter Initialization	LHQ Part 1: PLD use (modified) Read dosimeter data

Table 1: Participant visit schedule

CHAPTER 5: RESULTS

Specific Aim 1: Descriptive analysis

The first specific aim of this study was to characterize and describe the PLD use of a group of young adults through laboratory measures, datalogging measures monitoring behavior over time, and self-reported behavior on the LHQ. The descriptive results are described here for the entire subject group of 52 participants, looking at the results from each measurement type individually.

Laboratory measurements of CLL. In order to study how CLL changes as a function of background noise, a set of measurements of CLL was taken in the laboratory using the probe microphone. Participants were asked to set the volume to "the level that they like it" in the presence of varying noise conditions. Figure 1 plots the average CLLs as a function of background noise measured for the entire group of 52 subjects. Average CLLs are also reported in Table 2, where it can be seen that CLL increases as the background noise increases and the standard deviation of the average CLL decreases as the background noise increases. However the large standard deviations seen here (range: 7.8-14.2 dB) reflect significant variability in individual CLLs in noise. A one-way ANOVA found significant differences between the background noise conditions ($F[4,26]) = 23.13$, $p < .01$). Scheffe post-hoc tests did not show significant differences between any condition and its neighboring conditions; for example, no difference was seen between 60 dBA and either 50 or 70 dBA. However, significant differences were seen on the post-hoc tests for all other combinations ($p < .05$).

Noise Condition	Mean CLL (Std. Dev)	SNR (Std. Dev)	% of listeners >85 dBA
Quiet	74.1 dBA (14.2 dBA)		25%
50 dB Pink Noise	76.0 dBA (12.2 dBA)	30.5 dB (12.7 dB)	23.1%
60 dB Pink Noise	82.0 dBA (10.3 dBA)	24.7 dB (10.9 dB)	28.9%
70 dB Pink Noise	87.0 dBA (9.0 dBA)	19.7 dB (9.5 dB)	53.9%
80 dB Pink Noise	93.1 dBA (7.8 dBA)	15.8 dB (7.9 dB)	84.6%

Table 2: Average CLLs and signal-to-noise ratios (adjusted for earphone attenuation), with standard deviations.

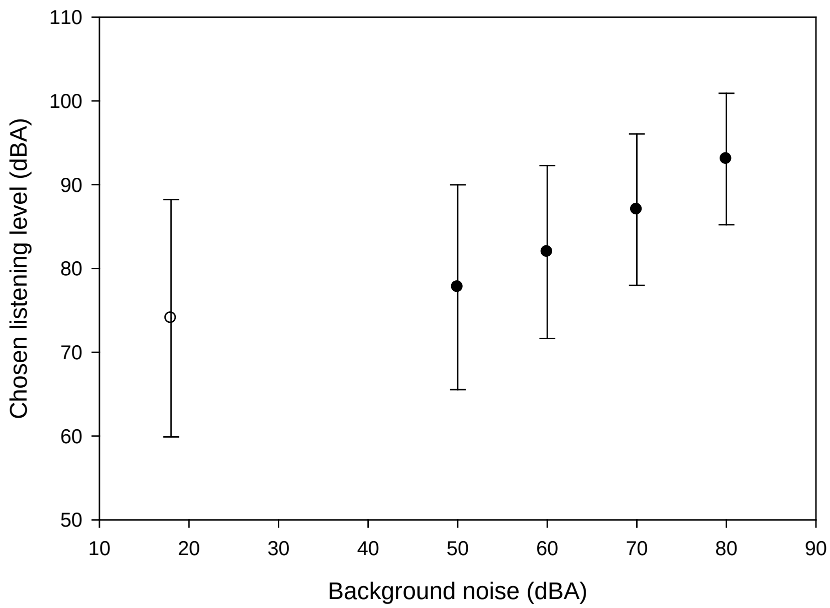

Figure 1: Average CLL plotted as a function of background noise level. Error bars represent 1 standard deviation around the mean.

Analysis of the CLL data can also take into account the attenuation provided by the earbuds. Earphone attenuation was calculated by calculating the difference in level between 60 dBA pink noise stimulus measured using the probe microphone in the open ear canal and the same stimulus measured with an earbud placed in the ear. The earphone was placed in the ear by the study participant, leading to some variation on the fit across participants. The average attenuation measured was 2.7 dB, with a standard deviation of 2.3 dB (range: 0-9.8 dB). Though the average attenuation is minimal, the large range means that in some cases with higher attenuations, a lower amount of background noise will reach the eardrum, which could impact the individual's CLL. Thus, Figure 2 shows the each subject's CLLs as a function of their individual estimated ambient ear canal noise level (EAECL), providing a view of the subjects' performance as a whole. The EAECL was calculated by subtracting the measured earphone isolation from the known background noise level to provide an estimate of the actual background noise level in the ear canal with the earphone in place. The EAECL removes the individual variability of the earphone isolation from the CLL, showing the true function of background noise on listening level. A linear regression line fit to these data explained 22 percent of the variance in the data set (r^2 = 0.22).

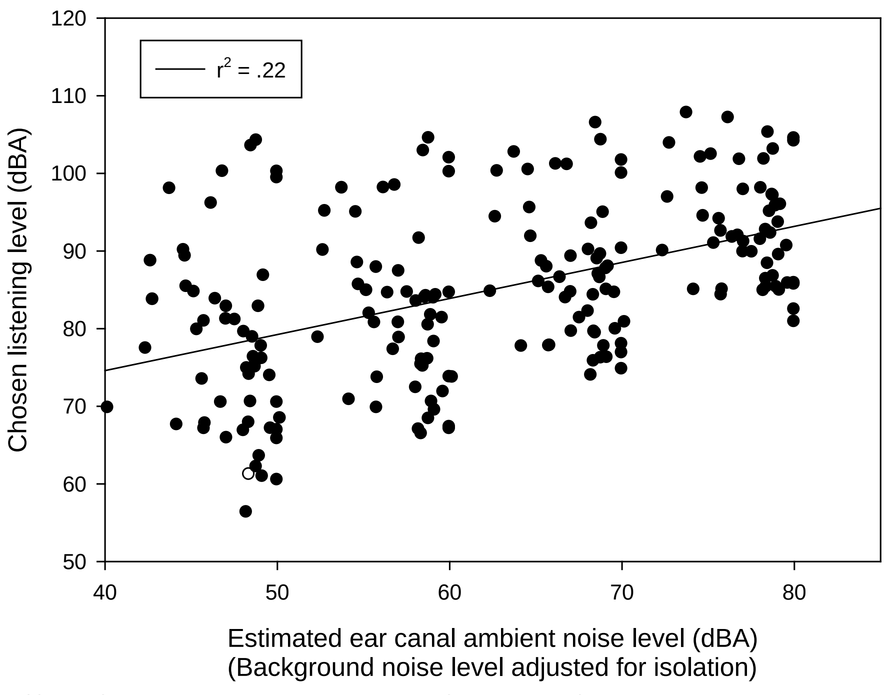

Figure 2: Diffuse-field equivalent CLLs as a function of the estimated ambient noise level in the ear canal for all trials in background noise, excluding the quiet condition. r2 = 0.22

The measured CLLs can also be evaluated in terms of their signal-to-noise ratios (SNRs), calculated by subtracting the EAECL from the individual CLLs. The SNR data, presented in

Table 2, show a wide standard deviation for each of the background noise conditions, suggesting that the data are widely distributed across the range of CLLs. Furthermore, to assess the reliability of the laboratory measurement technique, each measurement was completed three times for each subject. These repetitions showed excellent reliability, indicated by high correlations between the each of the trials (Trials 1,2: r = .933; Trials 2,3: r = .917; Trials 1,3: r = .930). Additionally, a repeated-measures ANOVA found no significant differences between the three repetitions ($F[2,25]$ = 1.63, p = .196).

Earphone datalogging measures. The experiment group, consisting of 24 subjects, had their listening levels monitored over the course of 7 days using the earphone datalogging system. This system reports an equalized level measurement (L_{eq}) every 3.75 minutes. For each subject, these individual L_{eq} measures were averaged into an average CLL. Then, the individual CLLs were averaged to create a group mean CLL of 71.7 dBA (standard deviation = 14.9 dBA). While this average is well within safe listening levels, the individual average levels ranged from 45.9 to 103.1 dBA. Figure 3 shows a histogram of the average CLLs, reflecting a somewhat bimodal distribution. Here, the most common average CLLs were between 55-60 dBA and between 80-85 dBA. The total listening time was also calculated by counting the number of non-zero 3.75 minute blocks recorded by the datalogging system for each subject. The average total time of PLD use as 12.1 hours, with a standard deviation of 8.0 hours (range: 3.2 - 32.5 hours).

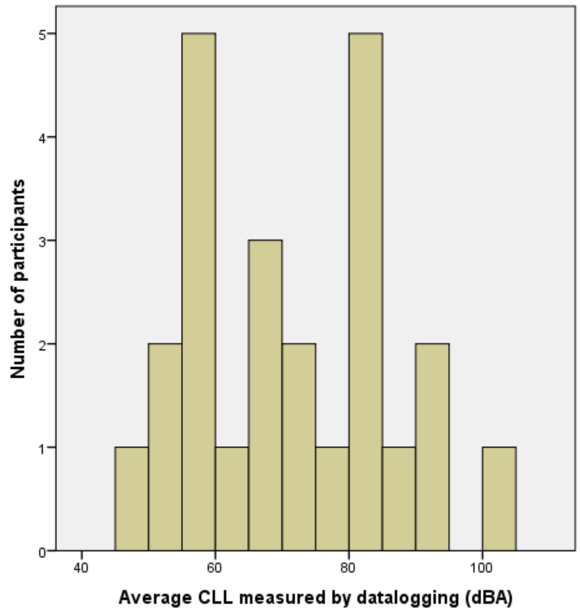

Figure 3: Histogram of average CLLs measured over a one-week time period by the datalogging system

Using the datalogging system, average CLLs and noise doses were calculated using OSHA and NIOSH DRCs for the experiment group. Each of these standards includes a different "threshold" level, a level under which any measurements are disregarded (80 dBA for NIOSH, 90 dBA for OSHA), as well as a different permissible exposure level and exchange rate. The data collected by the datalogging system consisted of a large set of L_{eq} measures taken every 3.75 minutes with no threshold specified. Thus, to calculate noise dose following the DRC standards, the raw data were manipulated to remove any measures below the appropriate threshold, either NIOSH or OSHA. These modified data sets were then used for any measures requiring a noise dose relative to a DRC.

Table 3 reports the average CLLs and noise dose measurement using the OSHA and NIOSH standard methods. Of note, the NIOSH average noise dose measure is substantially influenced by the presence of an outlier where one subject had a NIOSH noise dose of 31,754 percent. Because of this outlier, several other metrics were used to help understand this data set.

Reported in Table 3 are the medians of the subjects' CLLs and doses as well as the percentages of subjects who exceeded both 50 and 100 percent of their weekly noise dose. Here, it can be seen that the median noise doses are considerably lower than the mean, and thus the majority of subjects had PLD exposure that did not add substantially to their daily noise dose. The percentage data, though, shows that a small but substantial percentage of PLD users (16.7 percent) were exceeding 100 percent of their weekly noise dose. Also presented in Table 3 are the NIOSH and OSHA 8-hour time-weighted average (TWA) levels. A TWA is a similar metric to dose, calculated by exposure level and duration.

Measurement	Mean	Median	Std. Dev	Min	Max	>50%	>100%
NIOSH Dose (%)	1710.9	9.6	6494.2	0	31754	20.8%	16.7%
OSHA Dose (%)	168.4	0	559.3	0	2685.8	12.5%	8.3%
NIOSH Average L_{eq} (dBA)	82.0	80.3	6.5	75.8	98.1		
NIOSH 8-hour TWA (dBA)	76.9	76.0	12.6	56.4	103.0		
OSHA Average L_{eq} (dBA)	88.7	87.0	4.2	85.5	98.1		
OSHA 8-hour TWA (dBA)	74.7	71.9	15.8	56.2	102.1		

Table 3: NIOSH and OSHA average CLLs, Doses and time-weighted averages (TWAs) from the datalogged data for the experiment group. The percentages listed reflect the percentage of subjects who exceeded a 50 or 100 percent weekly noise dose.

Listening Habits Questionnaire. The LHQ, a questionnaire assessing listening habits and attitudes and beliefs towards PLD use and hearing loss, was administered to both the experiment and control groups for a total of 52 subjects. The results of the survey are reported in full in Appendix 2. However, several survey measures were of specific interest here. First, participants reported that they listened, on average, for 14.3 hours per week, though this mean is reflective of a wide range (4-50 hours) and a large standard deviation (10.6 hours). Subjects also were asked to provide the level at which they "usually" listen, reported on a 1-10 scale that was analogous to a PLD's volume control. On average, the subject group reported a usual volume control level of 6.8 (standard deviation = 1.6, range = 3-10).

The self-reported, scaled volume control levels were then converted into an estimated output level (in dBA) using previously collected data on PLD output levels (Portnuff et al, in press). These estimated output levels were calculated by using the regression equations presented in Table 4, where the choice of regression equation is dependent on the types of earphone used. Using these regression equations, the "usual" average CLL (CLL_{usual}) was calculated to be 82.1 dBA, with a standard deviation of 10.4 dBA Using this calculated CLL in combination with the self-reported listening time, a self-reported dose was calculated using the NIOSH DRC ($Dose_{usual}$). Noise doses are reported in Table 5, and a summary of the variables calculated from the self-reports and measurements is presented in Table 6 for reference.

Earphone Type	Regression equation
Earbuds	0.6143x+39.395
Isolator	0.6159x+42.561
Supra-aural	0.6147x+39.939

Table 4: Regression equations used to calculate CLLs from self-reported volume control levels from Portnuff et al (in press).

Measurement	Average	Std. Dev	Min	Max	>50%	>100%
$Dose_{usual}$ (%)	1840.6	6245.6	0	36152.5	32.7%	19.2%
$Dose_{vol}$ (%)	1864.3	6020.4	0	36152.5	38.5%	23.1%
CLL_{usual} (dBA)	82.1	10.4	57.8	104.1		
CLL_{vol} (dBA)	79.5	10.6	59.6	104.1		

Table 5. Self-reported CLLs and noise doses from the "usual" CLL and a CLL calculated by percentage of time spent at volume control increments from minimum to maximum.

Variable	Data Source	Subject group	Source question
$Dose_{usual}$	LHQ (self-report)	All subjects	"What volume setting do you usually listen at?" + "How long do you usually listen to your MP3 player each week?"
CLL_{usual}	LHQ (self-report)	All subjects	"What volume setting do you usually listen at?"
$Dose_{vol}$	LHQ (self-report)	All subjects	"How much time do you spend at 10% of the volume dial? 20%? 30%?..."
CLL_{vol}	LHQ (self-report)	All subjects	"How much time do you spend at 10% of the volume dial? 20%? 30%?..."
$Dose_{measured}$	Datalogging	Experiment group	
$CLL_{measured}$	Datalogging	Experiment group	

Table 6. Summary of variables reported in the text

Another question on the LHQ asked subjects to note the amount of time that they listened to their player at volume increments of 10 percent (i.e. how much time the PLD was used at 10 percent of the maximum volume setting, 20 percent of the maximum volume setting and so on). These time increments were then calculated into a NIOSH noise dose ($Dose_{vol}$) measured by summing the noise dose incurred at each volume increment as shown in Table 5. When averaged by the amount of time spent at each volume increment, the estimated average CLL was 79.5 dBA, with a standard deviation of 10.6 dBA. The average CLL_{usual} and CLL_{vol} reflect wide ranges, a presence of outliers, and high standard deviations that impact the mean levels.

The LHQ also asked participants to note the amount of time that they spent listening at several levels, using both a qualitative loudness scale and a level scale that compared sound levels to environmental sounds. Figure 4 shows the average percentage of time that subjects reported listening at qualitative increments from very soft to very loud. This figure illustrates that the average levels were between moderate and loud, with subjects spending little time at very soft or very loud levels. Figure 5 shows the percentage of time that subjects reported listening at levels from less than 40 dBA to greater than 100 dBA. For this question, participants were asked "how much time do you spend with your player set to the following levels", and a list of analogous descriptors for volume levels, such as "as loud as loud speech (70 dBA)" were included. Participants reported spending the most time listening at levels between 60 to 80 dBA.

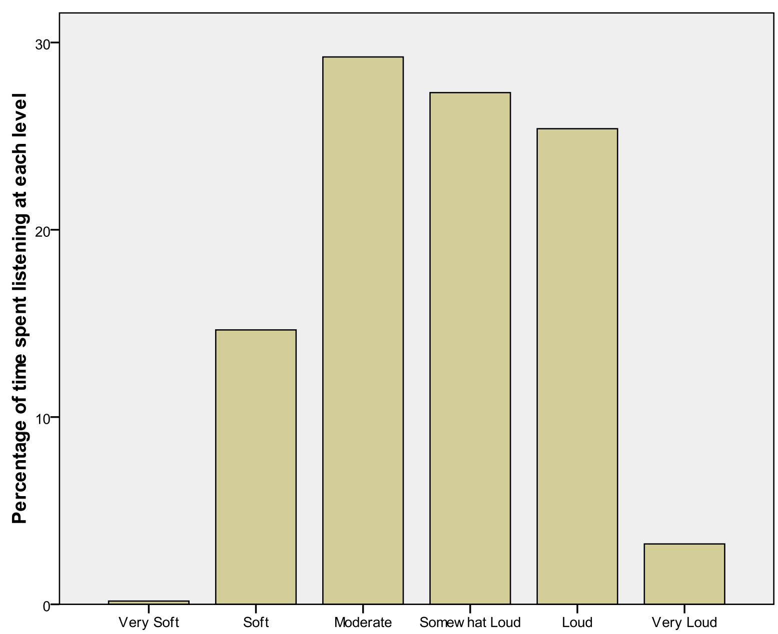

Figure 4: Percentage of time that subjects reported listening at several qualitative loudness levels

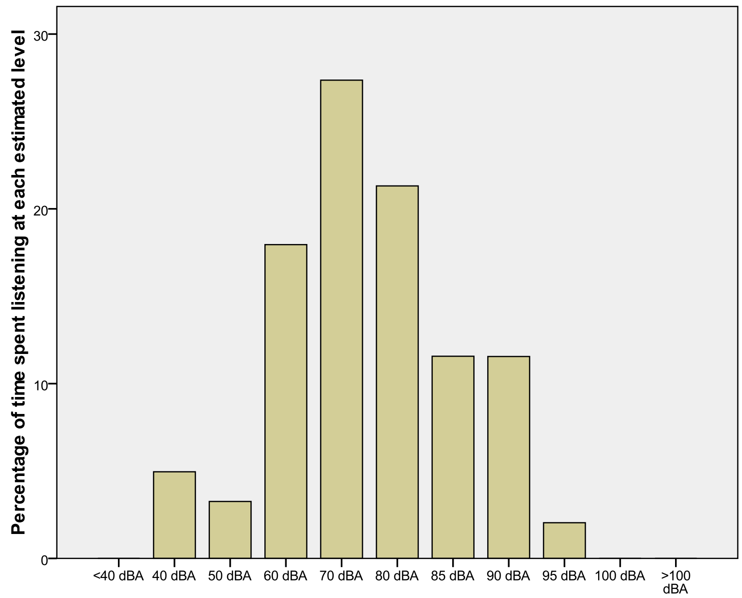

Figure 5: Percentage of time that subjects reported listening at levels ranging from less than 40 to greater than 100 dBA. Subjects were provided with real-world examples of each sound level.

Specific Aim 2: Relationships between laboratory measured, self-reported, and real-world data

The second specific aim of this study was to evaluate the relationships between laboratory measures, long-term datalogged measures and self-report measures of PLD use and listening behavior. To examine these relationships, self-report measures from the second experimental visit were used, as they looked back on the previous week, evaluating the same time period as the datalogging measures. For all datalogging measures, the NIOSH standard was used to calculate noise dose. For measures that compare datalogging measures to either self-report measures or to the laboratory measures, only data from the experiment group are reported, as the control group did not have their behavior monitored over time.

Self-report compared to real-world data. One primary aim of this study is to evaluate the accuracy of self-report questions in predicting actual music exposure levels. To establish these relationships, the self-reported CLL and dose measures were compared to the CLL and dose measures. These comparisons revealed several significant, moderate to strong Pearson's correlations among the participants in the experiment group, reported in Table 7. Moderate correlations were noted between the self-reported average CLL_{usual} and the average $CLL_{measured}$ ($r = .519$, $p < .01$), as well as the CLL_{vol} and the $CLL_{measured}$ ($r = .661$, $p < .01$). However, when the listening time is taken into account by calculating noise doses, these relationships were changed slightly. Similar to the CLLs, a strong correlation was present between the $Dose_{usual}$ and the $Dose_{measured}$ ($r = .813$, $p < .01$). This relationship was confirmed with a paired t-test, which identified no significant differences between the dose calculated by the $Dose_{usual}$ and the $Dose_{measured}$ ($t = .786$, $p = .44$). Looking at another dose metric, only a non-significant, weak correlation was seen between the self-reported $Dose_{vol}$ and the datalogged $Dose_{measured}$ ($r = .159$). However, no significant difference was seen between the $Dose_{vol}$ and the $Dose_{measured}$ on a paired-samples t-test ($t = .51$, $p = .61$).

	CLL_{usual}	CLL_{vol}	$Dose_{usual}$	$Dose_{vol}$
$CLL_{measured}$	.519**	.661**	.668**	.336
$Dose_{measured}$	.387	-.081	.813**	.159

Table 7. Correlation matrix between self-reported metrics and datalogged metrics of dose and CLL, compared at the second experimental visit. * = p < .05, ** = p< .01

Table 8 reports the mean doses for the experiment group for the two self-reported dose measures ($Dose_{usual}$ and $Dose_{vol}$) and the measured dose from the datalogging system ($Dose_{measured}$). Though the average self-reported CLLs suggest that listeners estimate lower exposure levels than they actually receive, these averages are skewed upward by high outliers. Because of this skewed distribution, the data can be better understood by evaluating the medians and the percentages of listeners who exceed either a 50 or 100 percent weekly noise dose. When looking at the 100 percent threshold, the self-report $Dose_{usual}$ is similar to that of the $Dose_{measured}$, though there is a substantially higher number of subjects who reported exceeding a 50 percent weekly noise dose than is reflected in the datalogged dose. The self-report for the $Dose_{vol}$ is higher than the datalogged dose for both the 50 and 100 percent metrics. As exceeding a 100 percent noise dose from any source of noise would increase an individual's risk for NIHL, these percentages can be viewed as the percentage of PLD users at risk for hearing loss from their typical usage patterns. Thus, in this sample, a higher percentage of subjects reported hazardous listening behavior than actually experienced hazardous levels.

	Average	Median	Std. Dev	Min	Max	>50%	>100%
$Dose_{usual}$ (%)	518.0	93.9	1742.6	0	9296.3	32.1%	14.3%
$Dose_{vol}$ (%)	834.3	64.2	2319.9	0	11282	42.9%	25.0%
$Dose_{measured}$ (%)	1710.9	9.6	6494.2	0	31754	20.8%	16.7%

Table 8: Dose calculations from the self-reported "Usual" CLL, the self-reported CLL by volume control increments and the measured dose from the datalogging system for the experiment group.

Similar trends were seen when looking at regressions of both dose and CLL. Figure 6 shows the self-reported CLL_{usual} in the left panel and the self reported CLL_{vol} in the right panel, both plotted against the average $CLL_{measured}$. Each of these CLL regressions explains a moderate amount of the variance in the measured data (r^2 = .37 for the CLL_{usual}, r^2 = .42 for the CLL_{vol}). Figure 7 shows the same data converted to noise doses using the exposure time, with $Dose_{usual}$ in the left panel and $Dose_{vol}$ the right panel, both plotted against the $Dose_{measured}$. Here, consistent with the correlations above, 66% of the variance in the measured CLL is explained by the $Dose_{usual}$ measure (r^2 = .66), but only 3% is explained by the $Dose_{vol}$ (r^2 = .03). Overall, the $Dose_{usual}$ measure seems to provide a strong prediction of the measured dose, though subjects tended to report slightly higher music exposure than they actually had.

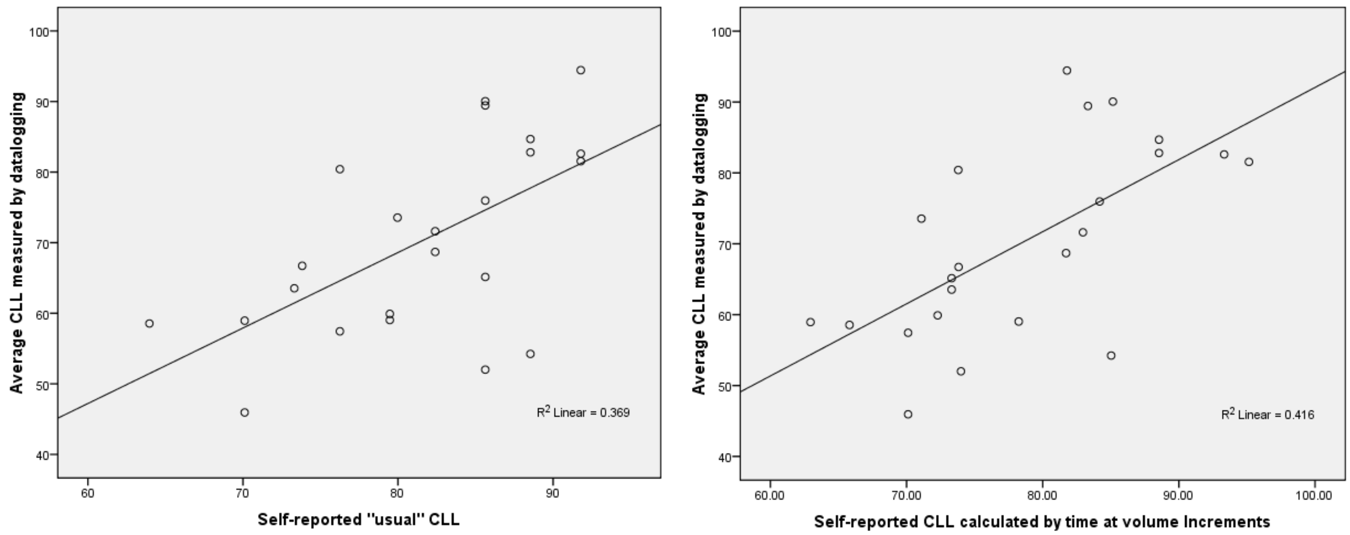

Figure 6: Scatterplots with regression lines of self-reported CLLs plotted against the average CLL measured through datalogging.

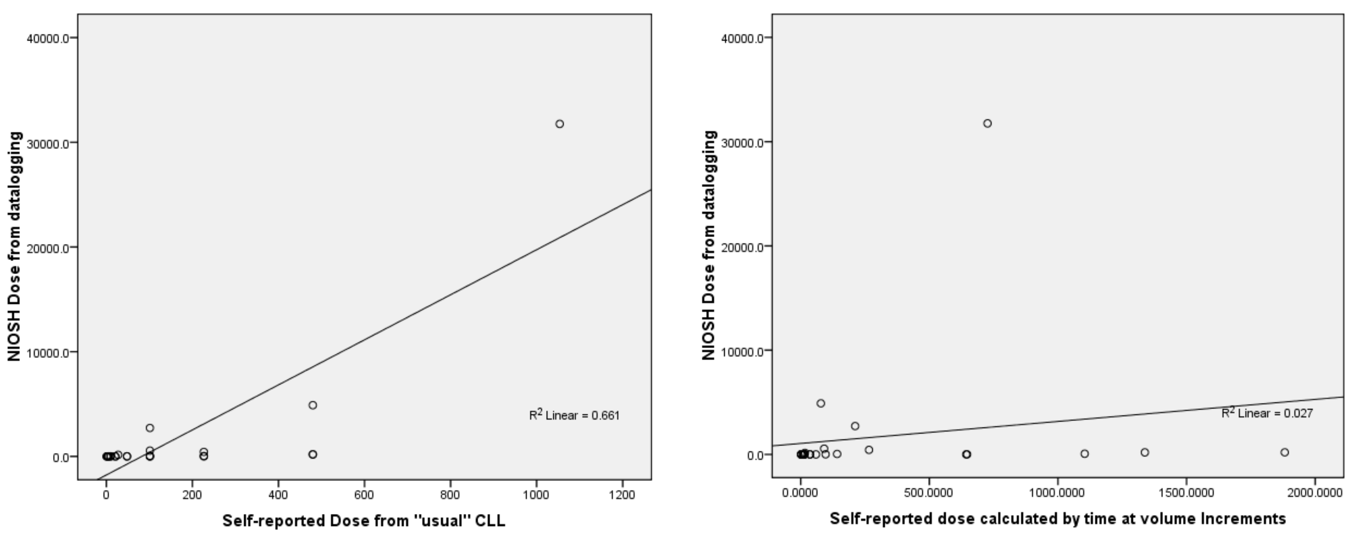

Figure 7: Scatterplots with regression lines of self-reported doses plotted against the average doses measured through datalogging.

The relationship between the datalogging measures of and the self-reported listening times for qualitative loudness and estimated listening levels was evaluated by looking at the Pearson's correlations between the $\text{Dose}_{\text{measured}}$ and each individual loudness descriptor and each listening level. A summary of these correlations is presented in Table 9. For the experiment group, the only correlation that reached statistical significance was between the $\text{Dose}_{\text{measured}}$ and the percentage of time that listeners reported listening at a “soft” level (r = .537, p < .01). No other qualitative loudness category had any more than a non-significant, weak correlation with the $Dose_{measured}$. Similar results were seen looking at the correlations between dose and self-reported listening time at various estimated levels for the experiment group, which are presented in Table 10. Here, a strong correlation was seen between the $Dose_{measured}$ and the amount of time that listeners reported listening at 40 dBA, characterized as “About the level of a quiet library” (r = .869, p < .01). No other listening level had any more than a very weak correlation with the datalogged dose.

% of time at level	$CLL_{measured}$	$Dose_{measured}$
Very soft	.156	-.050
Soft	-.006	.537**
Moderate	-.453*	-.214
Somewhat loud	.176	-.121
Loud	.234	-.129
Very loud	.330	.000

Table 9. Correlation matrix between time spent at various self-reported loudness levels and datalogged metrics of dose and CLL, compared at the second experimental visit * = p < .05, ** = p< .01

% of time spent at level	$CLL_{measured}$	$Dose_{measured}$
Quieter than a quiet library (<40 dB)	XX	XX
As loud as a quiet library (40 dB)	.365	.869**
As loud as rainfall on pavement (50 dB)	-.376	-.115
As loud as conversational speech (60 dB)	-.412*	-.112
As loud as a loud speech (70 dB)	-.251	-.180
As loud as a vacuum cleaner (80 dB)	.208	-.082
As loud as a blender (85 dB)	.268	-.069
As loud as a lawnmower (90 dB)	.178	-.087
As loud as a motorcycle (95 dB)	-.035	-.092
As loud as a chainsaw (100 dB)	XX	XX
Louder than a chainsaw (>100 dB)	XX	XX

Table 10. Correlation matrix between time spent at various self-reported listening levels and datalogged metrics of dose and CLL, compared at the second experimental visit. XX = No subjects reported listening at this level. * = $p < .05$, ** = $p < .01$

Additionally, for the experiment group, the actual listening time was calculated using the data from the datalogging system and compared to the self-reported total listening time. As reported above, the average measured listening time was 12.1 hours while the average self-reported listening time was 14.3 hours. A paired t-test showed no significant differences between actual and self-reported listening time (t = .920, p = .368). Thus, it can be inferred that the subjects in this study accurately reported their listening time.

Self-reported compared to laboratory and real-world CLLs. In order to examine the relationships between self-reported CLLs and the CLLs measured in the laboratory in various levels of background noise, an analysis looked at the entire group of 52 subjects. A large set of correlations were created between the CLLs measured for each background noise condition in the laboratory and the self-reported CLLs for both self-reported average CLL_{usual} and self-reported CLL_{vol}. Significant correlations were found between each laboratory background noise condition and both the CLL_{usual} and the CLL_{vol}, shown in Table 11. The strongest correlations were seen between the two self-report CLLs and the CLLs measured in the quiet conditions, though those correlations were not substantially different than those measured for the 50, 60 or 70 dBA background noise conditions. These correlations suggest that, as laboratory CLL increased, so did self-reported CLLs. However, each of the laboratory conditions was significantly related to the self-report measures, suggesting that no one laboratory condition best represented self-reported CLL.

Noise Condition	CLL_{usual}	CLL_{vol}	$CLL_{measured}$
Quiet	.733*	.695*	.740*
50 dB Pink Noise	.646*	.593*	.651*
60 dB Pink Noise	.643*	.572*	.697*
70 dB Pink Noise	.659*	.587*	.736*
80 dB Pink Noise	.478*	.411*	.603*

Table 11: Pearson's correlations between the CLLs measured in various laboratory noise conditions and self-reported "usual" CLL and the self-reported CLLs calculated by time reported to be spent at various volume increments. * = $p < .01$

Table 11 also reports the correlations between the CLLs in each background noise condition and the $CLL_{measured}$. Here, significant, moderate, positive correlations were seen between each of the background noise conditions and the average listening levels. Thus, as listening level in the laboratory increased, so did the measured CLL in the real world. However, as with the self-report levels, no single background noise condition was more strongly related to the datalogged, real-world CLL than any other condition.

Specific Aim 3: Impact of behavior monitoring on self-reported listening level

The third specific aim of this study was designed to identify any effects of monitoring behavior over time on self-reported listening behavior. In order to evaluate this aim, several comparisons were made between self-report measures completed before the monitoring period and after the monitoring period for both the experiment and control groups. To assess any changes over the monitoring period, paired-samples t-tests were completed for five self-reported variables: Listening time, CLL_{usual}, CLL_{vol}, $Dose_{usual}$, and $Dose_{vol}$. Looking at the entire study group, the paired-samples t-tests showed significant differences for all the variables ($p < .05$), with decreases in the mean listening time, CLL_{usual}, CLL_{vol}, $Dose_{usual}$, and $Dose_{vol}$ at the second measurement period.

When divided into experiment and control groups, these relationships become slightly different. For the experiment group, there were no t-tests that showed a significant difference between the self-reports recorded prior to and following the monitoring period ($p > .05$). However, for the control group, significant differences were seen in the reports from the first and second visit for listening time, CLL_{usual}, and in CLL_{vol} ($p < .05$). Overall, for both groups, the averages decreased for each variable from the first report to the second report.

Specific Aim 4: Relationships between LHQ and behavior

The fourth specific aim of this study was to examine the relationships between attitudes and beliefs about use of PLDs and hearing loss and listening behavior using the LHQ. The initial development and validation of the LHQ was completed with a group of teenagers by Portnuff and colleagues (in press), where it was found to have good internal validity and reliability. Portnuff et al created index variables that were associated with the HBM constructs forming the underlying design of the LHQ. In order to ensure that the LHQ is appropriate for the current population, a new validation was completed using an exploratory factor analysis and internal consistency analysis to verify the validity and reliability the HBM variables as underlying constructs. The factor analysis, designed to extract the underlying factors, was completed on the raw LHQ questions using a principal components analysis (PCA) with no rotation. Seven factors were identified with eigenvalues over 1.0, though no obvious elbow was noted in the scree plot to denote the most efficient number of factors. Use of the Kaiser rule would suggest that a model with seven factors would be the most efficient model to evaluate the data. However, the LHQ was designed around five constructs, and a closer analysis was completed for models with both seven and five factors. To look at these models more closely, a varimax (orthogonal) rotation was applied to the PCA data for both five and seven factors. In the model with five factors, loading for each factor was well differentiated by the LHQ constructs, with only two LHQ questions loading on to multiple factors. In the model with seven factors, the LHQ constructs generally load together on similar factors, though three LHQ questions have moderate loading on multiple factors. Across this analysis, the most parsimonious explanation comes from using the model with five factors, as the rotated component matrix generally confirms the underlying assumptions of the LHQ. Thus, the model with five factors was used for further analysis.

In order to simplify the data analysis, indices were created for each of the constructs of the LHQ by averaging the scores for each question in each construct into a single scale variable, similar to the process completed by Portnuff et al (in press). For example, the questions that evaluated susceptibility to hearing loss were combined into a single variable index of susceptibility. To assess the reliability of the scale variables created to represent each of the HBM constructs, Cronbach's alpha was calculated for each scale. Cronbach's alpha is a coefficient of internal consistency for a scale that measures how well a set of individual variables measures a single construct. For each scale variable, as reported in Appendix 1, Cronbach's alpha was 0.75 or higher for all scales except for the barriers to taking preventative action scale, which was slightly lower at .597. These high ratings of consistency indicate that each scale variable is well measured by its set of corresponding LHQ questions.

LHQ Scale Index	Chronbach's Alpha
Susceptibility to hearing loss from MP3 player use	.862
Severity of hearing loss from MP3 player use	.759
Benefits of taking preventative action	.860
Barriers to taking preventative action	.597
Self-Efficacy for taking preventative action	.760

Table 12: Internal consistency of the LHQ construct indices

Correlations and regression models. Table 13 reports the correlations between each of the HBM construct indexes for all subjects. Significant correlations were found between several variables, including a weak positive correlation between the Severity and Barriers scales, a moderate positive correlation between the Self-Efficacy and Benefits scales, and a moderate negative correlation between the Self-Efficacy and Barriers scales. Table 14 reports correlations between the HBM constructs and several measures of behavior including CLL_{usual}, CLL_{vol}, $Dose_{usual}$, $Dose_{vol}$, and $Dose_{measured}$. For these correlations, data for all 52 subjects was used for each set of correlations, except for correlations involving $Dose_{measured}$, where only the experiment group of 24 subjects was examined. In this table, significant, moderate negative correlations were seen between $Dose_{usual}$ and the Susceptibility index, and between the $Dose_{vol}$ and the Susceptibility index. Significant, moderate positive correlations were seen between the CLL_{vol} and the Barriers index as well as the $Dose_{vol}$ and the Barriers index.

	Susceptibility	Severity	Benefits	Barriers	Self-Efficacy
Susceptibility	1	.140	.108	.052	-.075
Severity	.140	1	.107	.278*	-.127
Benefits	.108	.107	1	-.117	.410**
Barriers	.052	.278*	-.117	1	-.454**
Self-Efficacy	-.075	-.127	.410**	-.454**	1

Table 13: Correlation Matrix for the LHQ HBM construct indices. * = p < .05, ** = p< .01

	CLL_{usual}	CLL_{vol}	$Dose_{usual}$	$Dose_{vol}$	$Dose_{measured}$
Susceptibility	-.161	-.188	-.396*	-.333*	.262
Severity	.119	.065	.068	.085	.255
Benefits	-.164	-.113	.051	.006	-.112
Barriers	.214	.353*	.323	.274*	.370
Self-Efficacy	-.028	-.072	-.047	-.033	-.455

Table 14: Correlation matrix between the HBM constructs and several behavioral variables, including four self-reported metrics and one measured metric. * = p < .05, ** = p< .01

In order to determine how well the HBM constructs predict self-reported listening behavior, several linear regression models were created. Table 15 presents the regression coefficients for each of these models, as well as Pearson's correlation of regression (r^2) and Cohen's f^2, an effect size measure. Seven models used the HBM constructs measured on the LHQ to predict the two CLL measures for all subjects, the two dose estimates for all subjects, and the datalogged NIOSH dose of the experiment group. As shown in this table, none of the models had strong explanatory value for the measures. The strongest model was that predicting the $Dose_{measured}$, which reflects only 24 subjects, and explained 30.9% of the variance, though the measurement of the $Dose_{usual}$ followed closely, explaining 27.8% of the variance. Large effect sizes were seen for both the model predicting $Dose_{measured}$ and the model predicting $Dose_{usual}$. As noted above, several of the HBM variables were moderately correlated, raising some concern of multicollinearity in these regression models. In order to monitor for effects of collinearity, variance inflation factors (VIF) were calculated for each coefficient in each model. The VIF is an index that measures how much the standard error of an estimated regression coefficient is increased due to collinearity. For example, a VIF of 2 would indicate that collinearity in the model may cause the regression coefficient to have a standard error twice that of a completely uncorrelated model. Typically, VIFs above 5 are considered cause for concern that the model could be impacted by collinearity (O'Brien, 2007). For the models listed above, no VIF greater than 1.8 was identified for any individual regression coefficient, suggesting that any impact of multicollinearity reported here is minimal.

	Standardized regression coefficients for each DV				
	CLL_{usual}	CLL_{vol}	$Dose_{usual}$	$Dose_{vol}$	$Dose_{measured}$
Susceptibility	-.156	-.188	-.425*	-.357*	.222
Severity	.116	.006	.002	.052	.067
Benefits	-.199	-.105	.239	.047	.069
Barriers	.243	.415*	.300	.316*	.131
Self-Efficacy	.167	.146	.024	.071	-.431
r^2	.119	.184	.278	.208	.309
Cohen's f^2	.137	.225	.385	.263	.447

Table 15: Coefficients from the linear regression models predicting self-reported CLLs and doses from several metrics. Each model includes each of the HBM scales measured on the LHQ (susceptibility, severity, benefits, barriers, self-efficacy). Data for all self-reported behavioral and LHQ variables was collected at visit 1, and the data for the $Dose_{measured}$ was collected over the week between visits 1 and 2. DV = dependent variable. * = $p < .05$

A close look at the most explanatory regression models in Table 15 shows an interesting pattern. First, the models predicting both the self-reported $Dose_{usual}$ and $Dose_{vol}$ have similar coefficients for most of the components. In these models, as susceptibility to hearing loss increases, dose decreases. However, when barriers to taking preventative action increase, the dose increases. For the model predicting $Dose_{usual}$, as benefits to taking action increase, so does $Dose_{usual}$. However, in the model predicting $Dose_{vol}$, benefits to taking action did not provide a substantive impact on the dependent variable. In both of these models, neither severity of hearing loss nor self-efficacy for taking action provide a substantial impact on the dependent variable. The strongest model, explaining 30.9% of the variance, was the model looking at the dose measured by datalogging for the experiment group only. In this model, as perception of severity increases, so does $Dose_{measured}$, and as self-efficacy for taking preventative action increases, $Dose_{measured}$ decreases.

Temporal precedence issues in the models

The above models that relate self-reported CLLs and doses to the LHQ constructs all have an issue when the temporal precedence is considered. Specifically, the LHQ constructs look at current attitudes and beliefs and the behavioral measures report usual behavior, which is truly reflective of *past* behavior. In order to help to ameliorate concerns that the model is temporally reversed, another set of regression models was evaluated looking at the self-reported behavioral measures collected during the second study visit, shown in Table 16. These regressions show the LHQ constructs that reflect attitudes and beliefs at visit 1 compared to participants' self-reports of listening behavior over the week between visits 1 and 2. In comparison to the models presented in Table 15, no one model accounts for more variance in the dependent variable than any other. Here, the highest percentage of variance accounted for was seen in the model predicting CLL_{usual}, where 18% of the variance is accounted for (r^2 = .182), and no model has more than a weak effect size. Similar to the previous models in Table 15, no VIF for any individual coefficient was greater than 1.6 for the models presented in Table 15, indicating that any effect of multicollinearity was minimal.

	Standardized regression coefficients for each DV			
	CLL_{usual}	CLL_{vol}	$Dose_{usual}$	$Dose_{vol}$
Susceptibility	-.127	-.232	-.230	-.288*
Severity	-.025	-.111	.048	.026
Benefits	-.225	-.160	.103	.098
Barriers	.382*	.293	.270	.282
Self-Efficacy	.316	.330*	.157	.184
r^2	.182	.181	.129	.163
Cohen's f^2	.222	.221	.148	.195

Table 16. Coefficients from the linear regression models predicting self-reported CLLs and doses from several metrics. Each model includes each of the HBM scales measured on the LHQ (susceptibility, severity, benefits, barriers, self-efficacy). All independent variables were measured at Visit 1. Dependent variable was measured at visit 2. DV = dependent variable * = $p < .05$

The use of models examining behavior at the second visit also allows the ability to control for past perceived behavior. This control was achieved by adding the dependent variable measured at the first visit, as shown in Table 17. These models reflect substantially higher r^2 values and strong effect sizes with the addition of the prior perceived behavior variable than without that variable. For each of the models, the change in r^2 is greater than .5, reflecting a large change in the variance accounted for in the model. The coefficients show that the primary factor in each model is the prior behavior factor. Correlations were then evaluated between each of the self-reported behavioral variables measured at the first study visit and its counterpart measured at the second study visit, presented in Table 18. Strong, significant correlations were seen between the visit 1 and visit 2 measures of each variable.

	Standardized regression coefficients for each DV			
	CLL_{usual}	CLL_{vol}	$Dose_{usual}$	$Dose_{vol}$
Susceptibility	-.008	-.072	.084	.016
Severity	-.114	-.116	.012	-.017
Benefits	-.103	-.071	.049	.059
Barriers	.197*	-.059	-.011	.013
Self-Efficacy	.188	.206*	.110	.123
DV at visit 1	.764*	.850*	.852*	.852*
r^2	.696	.770	.692	.738
Change in r^2	.514	.589	.563	.575
Cohen's f^2	2.29	3.35	2.25	2.82

Table 17. Coefficients from the linear regression models predicting self-reported CLLs and doses from several metrics. Each model includes each of the HBM scales measured on the LHQ (susceptibility, severity, benefits, barriers, self-efficacy). All independent variables were measured at Visit 1. Dependent variable was measured at visit 2. Also presented is the change in the r^2 with the addition of the DV measured at visit 1 into the models.
DV = dependent variable * = $p < .05$

	Correlation
CLL_{usual}	.806*
CLL_{vol}	.828*
$Dose_{usual}$	.816*
$Dose_{vol}$	.845*

Table 18. Pearson's correlations between each self-reported behavioral variable measured at visit 1 and its corresponding variable measured at visit 2. * = $p <.01$

CHAPTER 6: DISCUSSION

This study reported on data examining four specific aims related to PLD usage behavior, including the examination of the laboratory, self-reported, and real-world PLD usage, as well as relationships between these measures and listeners' attitudes to and beliefs regarding PLD use and hearing loss. In order to evaluate the results of this study, this discussion is divided into five sections, with the first four sections specifically evaluating each of the research questions, and the final section examining limitations of this study and future directions. Within each section, interpretation of the results and comparisons to previous research are provided, followed by an examination of the wider implications of the present data.

Specific Aim 1: Descriptive analysis

Laboratory measures. Overall, the laboratory measures reported here are consistent with the trends seen in previous research. As predicted, the measures of CLL in background noise found in this study, reflecting behavior of the entire subject group, show a consistent increase in CLL as background noise increases. Furthermore, the average CLLs here reflect large SNRs, with listeners choosing levels between 15 and 30 dB above the background noise level. In order to use these data to assess risk to hearing, we can consider the number of subjects who exceeded 85 dBA, a common threshold at which the risk of hearing loss due to overexposure begins to increase. As shown in Table 2, in 80 dBA of background noise, 84.6 percent of the group had a CLL that exceeded 85 dBA. This percentage is notable, as a background noise level of 80 dBA occurs in certain common environments, including buses, subways and airplane cabins. In these environments, a substantial percentage of the population would be expected to choose levels that could increase their risk for hearing loss, as exposure at levels greater than 85 dBA for extended durations could cause MIHL. Even in lower background noise levels, though, a substantial percentage of the population could be at risk for MIHL, as greater than 50 percent of subjects had CLLs that exceeded 85 dBA in 70 dBA of background noise.

The results of this study are consistent with Portnuff et al (in press) and Fligor and Ives (2006), in that average CLLs and the percentage of subjects whose CLL exceeded 85 dBA increased as a function of the background noise level. However, the average CLL for each background noise condition was substantially higher for the participants in this study than for those seen in either the teenagers of Portnuff et al (in press) or the doctoral students of Fligor and Ives (2006). These differences can be seen in Table 19, where the differences in CLL in each noise level ranged from 5.4 to 8.8 dB. Consequently, the average SNRs measured in this study are also larger than those of the group studied by Portnuff et al. Additionally, the current CLLs and SNRs also reflect a substantially larger standard deviation than that found in previous research. Though it is unclear exactly why this study showed a higher percentage of subjects exceeding 85 dBA than previous studies, there may have been a wider stratification of the sample from the local population, as this study recruited widely from the Denver, CO metropolitan area using primarily Craigslist.com. Using more constrained subject recruitment, Portnuff et al (in press) recruited teenagers from primarily the Boulder, CO area and University of Colorado community, and the population from Fligor and Ives (2006) consisted entirely of Optometry and Audiology doctoral students at the Pennsylvania College of Optometry (now Salus University). Though a sociodemographic analysis was not completed on these data, it is possible that the present subject group could be a more representative sample of the general population than previous studies.

Noise Condition	Current study mean CLL	Portnuff et al mean CLL	Difference
Quiet	74.1 dBA	68.3 dBA	5.8 dB
50 dB	76.0 dBA	70.6 dBA	5.4 dB
60 dB	82.0 dBA	74.6 dBA	7.4 dB
70 dB	87.0 dBA	79.3 dBA	7.7 dB
80 dB	93.1 dBA	84.3 dBA	8.8 dB

Table 19. Comparison of CLLs measured in the laboratory between the current study data and the CLLs measured in teenagers by Portnuff, Fligor & Arehart (in press).

Measured data. The results from the datalogging systems reveal several interesting trends in the listening habits of the experiment group measured over the course of a week. The histogram shown in Figure 3 shows a wide range of average CLLs measured by the datalogging. Of note, four of the 24 subjects (16.7 percent) listened at average CLLs that were greater than 85 dBA. The subjects' actual music exposure, though, is better represented through the dose metrics, which are calculated by combining listening duration and level, and are represented in Table 3. Of the group, 16.7 percent exceeded 100 percent of their weekly noise dose, and 20.8 percent exceeded 50 percent of their weekly noise dose calculated by the NIOSH DRC. Based on these results, a substantial percentage of the population who uses PLD is at risk for MIHL from their PLD use alone.

As the current study used a novel method of measuring actual music exposure, direct comparisons to previous research cannot be made. However, several studies used single measures of CLL in public places, combined with self-reported listening times, to provide a metric of exposure over time. Previous studies using this methodology report a wide range of percentages of PLD users exceeding 100 percent of their daily or weekly noise dose (see Table 20), including 51.9 percent measured by Levey, Levey and Fligor (2011) and zero percent measured by Epstein, Marozeau and Cleveland (2010). The data from the present study seem to fit in the middle of the range of the previous studies. However, it should be noted that the datalogging in the present study reflects PLD usage over time, which includes all of a user's listening environments, while the other studies compared here reflect a single measurement completed in a public place. A single measurement, while providing a good snapshot of usage, cannot capture the complete activity of the PLD user.

Study	% of subjects exceeding 100% noise dose	Location
Current study	16.7%	Monitoring over the course of 1 week, Denver/Boulder, CO
Levey, Levey & Fligor (2011)	51.9%	Urban university campus, New York City, NY
Williams (2005)	25%	Busy streets, Melbourne and Sydney, Australia
Williams (2009)	17%	Busy streets, Brisbane, Canberra, Australia
Epstein, Marozeau & Cleveland (2010)	0%	Various locations, Boston MA

Table 20. Comparison of measured data collected in this study to previous studies.

LHQ data. The listening habits data collected by self-report reveal a subject group with wide-ranging listening behavior and attitudes. Consistent with most of the previous literature, subjects reported an average listening time of about 2 hours per day (14.3 hours per week), though a small number of individuals (n = 3) reported listening times between 30 to 50 hours per week. However, for both the Dose_{usual} and the Dose_{vol}, the percentage of listeners who reported noise doses greater than 100 percent was higher than in previous studies. Further, the two methods of quantifying listening habits through estimated loudness and estimated sound level show somewhat wide distributions, as seen in Figures 4 and 5. Figure 4 shows a fairly equal percentage of time spent at moderate, somewhat loud and loud levels, with no one level standing out as representative. Figure 5 shows a somewhat skewed distribution of the amount of time spent at various listening levels, as qualified by comparable sound levels. The distribution is centered at the 70 dBA level, but is positively skewed, as the scale on the abscissa is categorical rather than linear. Indeed, analysis of the distribution shows that listeners reported the majority of listening time (60.7 percent) at levels between 70-90 dBA.

In comparison to previous data, the self-reported listening habits are generally similar to those found through previous survey research. The self-reported listening time reported in this study is consistent with the general trends reported in previous surveys as well, with an average listening time of about 2 hours per day, but with a wide range and some outliers listening for longer periods of time (Danhauer et al, 2009; Hoover & Krishnamurti, 2010). With regard to the qualitative reports of loudness, this study found a similar distribution for the categorical descriptors of PLD loudness to those of Torre (2008). Looking at the $Dose_{usual}$ calculation, the present study found a higher percentage of listeners who exceeded a 100 percent weekly noise dose than in the teenagers of Portnuff et al (in press).

Implications. The results of this study provide a comprehensive view of the listening habits of young adults, including the first long-term monitoring of PLD users as well as in depth quantitative survey measures of listening behavior. It also describes a novel method for completing this type of long-term monitoring, using a commercially available personal noise dosimeter. This method could also be adapted to measure any type of earphone producing any type of sound. Furthermore, the study provides validation of self-reports via the LHQ as a method of measuring noise dose from music exposure, and thus the risk of MIHL. The methods used here, with the exception of the laboratory measures, are relatively low-cost measures that could be applied to future research or clinical practice with only minor modifications.

As the ultimate goal of any exposure study is to determine the population risk from overexposure to the risk behavior, comparisons of exposure to DRC are the best way to evaluate risk. Looking at the datalogging data in Table 3, this study found that 16.7 percent of listeners exceeded 100 percent of their weekly noise dose, and 20.8 percent exceeded 50 percent of their weekly noise dose, both based off of the NIOSH DRC. When considering the acceptable noise dose due to PLD use alone, other daily noise exposure, including both occupational and other recreational exposure, should be taken into account. As young adults might obtain a portion of their noise dose from other activities in a given day, recommending limits that reach 100 percent of a daily noise dose from PLD alone is not appropriate. A lower cutoff for exposure due to PLD use, such as a 50 percent noise dose, may be a better recommendation. For persons who are known to work in noisy environments, the allowable dose from recreational noise exposure may be even lower than 50 percent. Certainly, more research is needed to determine what cutoff level is the most appropriate for a recommended limit for PLD use in young adults. However, assuming that a 50 percent noise dose is a reasonable threshold for safe use of a PLD, this study suggests that a substantial percentage (20.8 percent) of listeners are putting themselves at risk for MIHL with their current usage patterns.

Specific Aim 2: Relationships between laboratory measured, self-reported, and real-world data

The second specific aim of this study was designed to examine the relationships found between the measurements completed in the laboratory, the datalogging measures, and the self-report measures on the LHQ. Interestingly, the results reflect a considerable range of relationships between each type of measurement presented. First, we can look at the datalogging measures in order to determine which self-report question most accurately captures real-world behavior. In this case, the measures of CLL and dose that were best correlated to the measured data were those resulting from the simplest question that asked how loud and for how long listeners usually listened, calculating $Dose_{usual}$. The linear regressions presented indicate that the strongest predictor of behavior was the dose calculated by that simple question, accounting for 66 percent of the variance in the data. However, using this metric, subjects still tended to overestimate their own exposure slightly, and the percentage of subjects who reported greater than a 50 percent noise dose was substantially higher than measured data. Looking at the percentage of subjects who exceeded 100 percent noise dose, the self-report and measured data are similar, indicating that the amount of overestimation did not result in large changes in estimated noise dose. Overall, though, the question that best captured PLD users listening behavior was the simplest question. Thus, this question may be the best choice for use as a behavioral descriptor for future analyses of survey-type data.

Consistent with the previous data on teenagers from Portnuff et al (in press), the strongest correlations between self-reported CLLs and the CLLs measured in the laboratory were found for the quiet condition. However, in this dataset, all correlations between the self-reported CLLs and each of the background noise conditions were significant, whereas those measured in teenagers were only significant for the quiet condition. Similar results were seen for the correlation between the laboratory CLL conditions and the datalogged CLLs. Thus, it cannot be inferred that the CLL measured in one laboratory condition is more representative of real-world behavior than any other.

Implications. The results of this study provide several interesting differences between the types of measurements completed. First, correlations were found between each of the laboratory conditions and both the laboratory and datalogged CLL measures. Perhaps, in this case, the datalogged behavior and the self-reported behavior are reflective of different underlying constructs than the laboratory behavior. Certainly, behavior in the laboratory is specific to each background noise condition, which is an artificially created environment. In the real world, background noise may fluctuate, or listeners may change their listening levels as the environment dictates.

Looking at the comparison between the datalogged measures and the self-report measures, the most accurate self-report was the question that calculated noise dose from the participant's usual listening level and usual duration of listening. Certainly, it makes sense that a measure of exposure that takes both level and time (dose) into account would be a stronger predictor of datalogged dose than a measure that only measures level (CLL). However, it is somewhat surprising that $Dose_{vol}$ predicted very little of the variance in the measured dose, as was expected. Nevertheless, as the $Dose_{usual}$ metric was the strongest predictor, it follows that this set of questions should be considered the best to use as a self-reported behavioral metric on future surveys. Though subjects tended to slightly overestimate their individual noise exposure when responding to the $Dose_{usual}$ question, their overall performance on this question was fairly accurate compared to the datalogging measures.

This study provides two important contributions to the literature. First, it reports on the development of a wearable dosimeter for field measurements that provides a gold standard for future studies of PLD use. However, the measurement technique using the dosimeter is somewhat time-consuming to integrate in to some types of studies. Thus, this study establishes that the $Dose_{usual}$ metric is an accurate question that can explain actual behavior. For future survey-based research, this question can be used as an efficient, evidence-based proxy for the gold standard of field measurements. This study also provides some credibility to previous studies that have used this same type of methodology in survey measures (Danhauer et al., 2009; Hoover & Krishnamurti, 2010), and provides a framework for accurate future use of self-report to quantify noise dose from PLD use.

Specific Aim 3: Impact of behavior monitoring on self-reported listening level

The third specific aim of this study was designed to observe any changes in self-reported listening behavior that may be due to the act of monitoring behavior over time through datalogging. No specific changes in self-reported behavior were found for the experiment group who underwent monitoring that were not seen in the control group. Interestingly, though, a decrease in self-reported CLL and Dose was noted for the entire study group between the first and second visits. These decreases in CLL and Dose may suggest that the act of asking listeners to consider their listening may lead to some decrease in reported listening level. Alternately, the wording of the question reflects some temporal discrepancy, as the first question asked about the listener's usual behavior, while the second question asked specifically about the week between study visits. Assuming that the week between study visits was generally representative of typical behavior, the overall decreases in CLL and Dose may reflect that subjects estimate higher "usual" exposure, while asking about a more specific monitoring period results in lower exposure estimates.

Additionally, with the division into experiment and control groups, statistically significant decreases in CLL and listening time were noted only for the control group, and not for the experiment group, though non-significant decreases in CLL and Dose were noted for both groups. Though it is interesting that the control group showed some behavior change over time, and the experiment group did not show similar change, it is unclear why this decrease in CLL may have occurred. It is possible that people, in general, overestimate their listening level and listening time, but upon monitoring their levels more carefully, find that they actually listen at slightly lower levels. Potentially, the control group may have monitored their use slightly more carefully, but these results do not specifically reflect an impact of the datalogging on self-report.

Specific Aim 4: Relationships between LHQ and behavior

The final specific aim of this study was designed to examine the relationships between the attitudes and beliefs expressed in the LHQ and the self-reported or measured behavior. These relationships are demonstrated in the regression models relating the self-reported and measured doses to the HBM constructs in the LHQ presented in Table 15. Each of these models has some weak to moderate explanatory value in explaining their behavioral outcomes by HBM variables when all variables were measured at the same time. The models relating the self-report measures are consistent with the idea that, if individuals believe that they are more susceptible to hearing loss, or if they perceive fewer barriers to taking preventative action, they will show decreases noise exposure. However, the finding that an increase in the benefits of taking preventative action is related an increase in noise dose would be counter to the expectation that increased benefits would lead to decreased risk behavior.

In contrast, the model predicting the measured dose shows a considerably different set of coefficients than the models predicting the self-reported behavioral variables. In this model, an increase in an individual's perception of self-efficacy for taking preventative action is related to a decrease in the individual's noise exposure. This finding is consistent with the underlying premise of the HBM, that if a person feels increased self-efficacy for taking preventative action, they will be more likely to take that preventative action. However, the model also shows that an increase in perceived susceptibility to MIHL is related to an increase in noise dose, which is in opposition to the hypothesized directionality, as the HBM predicts that increased susceptibility to a health risk would lead to a decrease in the risk behavior. However, it should be noted that this model predicting the measured dose reflects data from only 24 participants, compared to the 52 participants in each of the self-report models. Moreover, a temporal inconsistency exists with this model. The measurement of beliefs via the HBM constructs were completed at the first visit, while the datalogged dose was collected over the week following the HBM constructs. For the self-report models, the behavior measures were collected at the same time as the measures of attitudes and beliefs. The temporal paradox and limited sample size may impact the generalizability of the data from the model predicting the measured data.

Overall, the model predicting dose from the single question measuring $Dose_{usual}$ from the self-reported usual listening level and listening time provided the best prediction and largest effect size for a self-reported behavioral variable. The superiority of this single question is consistent with the previous data showing that $Dose_{usual}$ was more predictive of the measured data than the question asking for multiple inputs of time spent at volume control increments. However, neither of the models looking at self-reported CLLs had a very strong explanatory value, and both had only moderate effect sizes. Interestingly, the lack of strong predictive value for CLL is in strong contrast to the data from Portnuff et al (in press), where the same questionnaire posed to teenagers predicted 69 percent of the variance in CLL_{usual}. Dose measures were not evaluated in the regression models by Portnuff et al (in press). While the present study had a larger sample size than the previous study (52 versus 29), it is unclear why the teenagers' beliefs were much more predictive of CLL_{usual} than those of the young adults in this study.

Further research with a larger subject population might help to understand why CLL_{usual} was predictive for teenagers, but not for young adults.

In order to address the temporal paradox created by comparing past self-reported behavior to present beliefs, several models were presented that looked at behavior reported at the second study visit, reflecting the participants' experience over the time between the first and second visits. While these models, presented in Table 16, do provide a more logical time-order, none of them account for a large amount of variance in the behavioral variables. Moreover, unlike the models looking only at the first study visit, in these models no one model stands alone as the strongest. Several possible reasons could explain the weak relationships seen in these models. First, it is possible that the independent and dependent variables here are measuring different time periods. At the second study visit, the CLL and dose metrics were calculated from questions that asked about behavior solely across the previous week, rather than the "usual" behavior evaluated at the first study visit. It is possible that the previous week was, overall, not representative of usual behavior, or that there was some response bias from the requirement to monitor one's behavior. While no specific differences were noted between the experiment and control groups looking at the effect of the datalogging on self-report, there was a significant change in self-reported listening behavior across the entire group from visit 1 to visit 2. Thus, it is possible that participants did not experience their "usual" behavior during the week between study visits. An additional explanation for the poor ability of the LHQ to predict CLL and dose in these models is that the self-reported measures are actually measuring different underlying constructs at each time point. It is possible that the measurement at visit 1 reflects a participant's perceived behavior, while the study triggered participants to self-monitor and report their actual behavior at the second visit. In this case, the perceived attitudes and beliefs may better reflect the perceived behavior than the actual behavior. However, the limited data from the experiment group looking at the model predicting $\text{Dose}_{\text{measured}}$ from the LHQ constructs would suggest that the attitudes and beliefs can be strongly associated with actual behavior, as a larger amount of variance was accounted for by the model that predicts $\text{Dose}_{\text{measured}}$.

When past behavior from the first visit is added in to the models as a control, Table 17 shows that a large proportion of the variance in the corresponding self-reported listening behavior at the second visit is accounted for. However, there is a strong correlation between the self-reported listening measured at the first and second visit for each variable. As the behavioral questions from the first visit asked about "usual" listening behavior, it follows that the listening behavior reported over the study week would be similar to the "usual" behavior, as indicated by the strong correlations. Thus, it is not surprising that these models would be dominated by past behavior, and that the addition of the "usual" listening behavior would explain much of the variance in the behavior reported at the second visit. These models indicate that knowledge of past PLD use behavior is strongly associated with future PLD use behavior.

Implications. This study provides validation for the use of the LHQ as a tool to measure the relationships between the attitudes and beliefs about hearing loss from PLD use and the listening behaviors of young adults. In combination with the previous research of Portnuff et al (in press), the LHQ shows strong internal validity and reliability. For the populations studied, the LHQ has good external validity as well, though the external validity is limited by the extent of the implementation of the LHQ to date. Further evaluation of the LHQ with a larger, more diverse population will provide an improvement in the generalizability of the results. This study also found that the use of noise dose as a behavioral variable in the LHQ provides a strong metric for understanding noise exposure.   With the finding that the self-reported $\text{Dose}_{\text{usual}}$ was the most accurate measure compared to the datalogging measures, it is not surprising that the model predicting $Dose_{usual}$ from the HBM constructs was the most predictive model of those models predicting self-reported behavioral variables. The addition of a $Dose_{usual}$ calculation to future implementations of the LHQ is strongly advisable.

Direct interpretation of the models presented here could provide some direction to the development of educational interventions. Specifically, the model predicting $Dose_{usual}$ would suggest that a focus on changing beliefs to increase the perception of susceptibility to hearing loss may help decrease exposure levels. This is consistent with the findings of Widén and Erlandsson (2007), who identified that individuals who feel more vulnerable to hearing loss were more likely to take preventative actions. Even though young adults may recognize the impacts or severity of hearing loss, they may not feel susceptible to hearing loss, a disorder that occurs slowly over years of exposure. Both the interviews of Vogel et al (2008) and the theoretical model of Widén (2006) suggest that a sense of vulnerability (i.e. susceptibility) comes from experience with the consequences of hearing loss. Fortunately, though, a majority of people surveyed were willing to take preventative action to reduce their risk for hearing loss, if they knew they were putting themselves at risk (Hoover & Krishnamurti, 2010). Interventions could be designed to show individuals that their actions in the present might make them more likely to incur a hearing disability in the future.

Furthermore, the modeling in this study suggests that a decreased perception of barriers to taking preventative action is related to decreased noise dose. Thus, interventions could also be targeted to teaching PLD users how to listen safely in their daily environments without compromising their listening experience. In the same vein, Widén and Erlandsson (2007) also found that barriers, primarily those social in nature, decreased the likelihood of taking preventative actions. To date, though, no specific interventions aimed at reducing PLD exposure have been reported in the literature.

Comparisons of the attitude and belief data between the present study and others in the same domain are difficult to complete, as the field of hearing loss prevention has a dearth of studies employing the HBM. However, looking at other health risk behavior literature shows some similar patterns to those seen in this study. Rundall and Wheeler (1979) found significant, positive relationships between both susceptibility to illness and barriers to seeking preventative care and the likihood of seeking preventative medical care. Similarly, Weinberger et al (1981) found that increased perceived susceptibility to disease was significantly related to a decrease in smoking behavior. Looking at a larger number of studies, a meta-analysis of studies using the HBM by Janz and Becker (1984) identified that, for preventative health behaviors, susceptibility, benefits and barriers were most frequently cited as significant factors. As this study found significant results for both susceptibility to MIHL and barriers to taking preventative action, the results seen here are consistent with other studies utilizing the HBM to examine preventative health behaviors.

Limitations and future directions

This study has several limitations. First, the subject population, while well stratified by age and gender, represented a specific age group of PLD users. Further study of a larger group, with an evaluation of a wider age range of PLD users may help to better generalize PLD use behavior to the larger population. Additionally, the findings of this study suggest that the number of PLD users who listen at levels that would increase their risk for hearing loss is a somewhat small percentage. Due to time and funding constraints, the experiment group who underwent long-term behavior monitoring was limited to 24 listeners. Having a larger sample size for these datalogged measures would help to better refine the percentage of users who are actually at risk. Alternatively, large samples of self-report data could be collected by survey only, with the knowledge that listeners tend to overestimate their listening habits slightly. Moreover, location and personal activities play a role in PLD usage behavior, as exposure to high-level background noise will typically cause a listener to choose higher levels. For example, two studies measuring CLLs in public places in New York and Boston found very disparate findings, with the New York study finding 51.9 percent of listeners exceeding 100 percent of a weekly noise dose, while the Boston study found no listeners exceeding 100 percent noise dose (Levey, Levey & Fligor, 2011; Epstein, Marozeau & Cleveland, 2010). As far as can be determined from the published methods of these studies, the major functional difference between them was in the location studied.

Looking at the attitudes and beliefs reported on the LHQ, extrapolation of the findings of the regression models to the general population should be done with care. Though recruitment was completed from a wide area, only very limited socio-demographic analyses were completed on the subject group, and no attempt was made to evaluate or stratify the sample for ethnicity, education level, or socioeconomic status. Further evaluation of the LHQ is needed, with the addition of questions collecting socio-demographic information that would allow the examination of differences in attitudes and beliefs between varying demographics. Moreover, the LHQ should be implemented in a larger scale, to allow for stronger statistical analyses, and the addition of a variable looking at intended behavior may help to reduce the temporal precedence issues noted earlier. Future work could also include the addition of questions assessing intentions to take preventative actions, especially if combined with any type of educational intervention. Additionally, future studies in this area should consider expanding the LHQ to include a standardized scale of young adults' risk-taking behavior as suggested by Bohlin and Erlandsson (2007) or sensation-seeking behavior (Zuckerman et al., 1978). The LHQ might also be expanded to look at previous experience with hearing loss as a mediating factor for both susceptibility and severity to hearing loss, or as an internal cue to take preventative action.

CHAPTER 7: CONCLUSIONS

The primary goals of this study were to understand how people use PLDs, how their usage pattern contribute to the risk of MIHL for listeners, and how attitudes and beliefs about PLD use relate to listening behavior. The study reported on a novel method for monitoring listening behavior over time, providing accurate measures of listening habits that were previously unavailable in the literature. Additionally, the study provides validation and support for the use of the LHQ as a research tool to understand the relationships between attitudes and beliefs and listening behaviors in the context of the Health Belief Model.

In the laboratory, listeners increased their CLLs as background noise increased, with 84.6 percent of listeners choosing levels above 85 dBA in the presence of 80 dBA of background noise. Using the long-term monitoring system, 16.7 percent of the study subjects accrued more than 100 percent of their weekly noise dose from PLD use alone. Comparisons of monitored data and self-reports showed that these subjects tended to overestimate their exposure slightly, but were relatively accurate in their estimates of their personal PLD exposure. The most accurate question was one asking PLD users to report both their listening duration and their usual listening level as a percentage of the volume control. Additionally, there was no systematic impact of the long-term monitoring on the subjects' self-reported listening behavior, suggesting that the monitoring techniques can be used without causing significant response bias.

When multiple regression models were used to determine the relationships between attitudes and beliefs and actual behavior, the most predictive models were those predicting both self-reported and measured noise dose, with much greater predictive value than those models predicting CLL alone. An examination of these models suggests that increasing an individual's perception of susceptibility to hearing loss and decreasing the perception of barriers to taking preventative action could lead to decreased music exposure and lower risk for MIHL. Furthermore, the LHQ showed good internal validity and reliability, positioning the LHQ to be used as a research tool for understanding the impact of attitudes and beliefs on listening behavior, as well as a potential tool for measuring changes following clinical interventions.

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APPENDIX 1: LISTENING HABITS QUESTIONNAIRE: PART 1

How long do you typically listen to your MP3 player during a **day**?

______________ hours -OR- _______________ minutes

How many hours do you typically listen to your MP3 player during a **week**?

______________ hours

What's your favorite type of music? (circle one)

☐ Alternative	☐ Rap	☐ Pop/Top 40
☐ Rock	☐ Country	☐ Classical
☐ Hard Rock	☐ Dance/Techno	☐ Other: ______________

When you listen to your MP3 player, what volume setting do you **usually** listen at? (Circle your typical level)

1 Low Volume	2	3	4	5	6	7	8	9	10 Maximum Volume

In a typical week, how much time do you listen to your player at:

10% of maximum volume	______	hours
20% of maximum volume	______	hours
30% of maximum volume	______	hours
40% of maximum volume	______	hours
50% of maximum volume	______	hours
‘ 60% of maximum volume	______	hours
70% of maximum volume	______	hours
80% of maximum volume	______	hours
90% of maximum volume	______	hours
100% of maximum volume	______	hours

In a typical week, how much time do you listen to your player at:

Very Soft volume	______	hours
Soft volume	______	hours
Medium volume	______	hours
Somewhat Loud volume	______	hours
Loud volume	______	hours
Very Loud volume	______	hours

In a typical week, how much time do you spend with your player set to the following volume levels:

Quieter than a quiet library (<40 dB)	_______	hours
As loud as a quiet library (40 dB)	_______	hours
As loud as rainfall on pavement (50 dB)	_______	hours
As loud as conversational speech (60 dB)	_______	hours
As loud as loud speech (70 dB)	_______	hours
As loud as a vacuum cleaner (80 dB)	_______	hours
As loud as the cabin of an airplane (80 dB)	_______	hours
As loud as a blender (85 dB)	_______	hours
As loud as a lawnmower (90 dB)	_______	hours
As loud as a motorcycle (95 dB)	_______	hours
As loud as a chainsaw (100 dB)	_______	hours
Louder than a chainsaw (<100 dB)	_______	hours

Where do you like to listen to your MP3 player **using earphones**? (check all that apply)

- ☐ At school in class
- ☐ Walking on the street
- ☐ Exercising outside
- ☐ Exercising at a gym
- ☐ On a bus
- ☐ On light rail
- ☐ In a car
- ☐ Studying in a quiet room
- ☐ Watching TV
- ☐ While sleeping
- ☐ Riding a bicycle
- ☐ Other: ____________________________

In a typical week, how much time do you listen to your player **using earphones** while you are:

On a public transit	______	hours
In a car	______	hours
Exercising outside	______	hours
Exercising at a gym	______	hours
Walking on the street	______	hours
In a quiet room	______	hours
Watching TV/movies	______	hours
While sleeping	______	hours
Riding a bicycle	______	hours

What type of earphones do you usually use? (circle all that apply)

- ☐ Earphones that rest on top of your ears
- ☐ Earbuds (like the earbuds that come with an iPod)
- ☐ In-ear earphones (fit inside your ears like an earplug)

Do you use earphones that are specially designed to block out background noise? (circle one)

- ☐ Yes
- ☐ No

When do you change the volume on your MP3 player? (check all that apply)

- ☐ When the background noise in the room gets louder or softer
- ☐ When someone starts talking to another person
- ☐ When someone starts talking to me
- ☐ When a car passes me on the street
- ☐ When a song that I like comes on
- ☐ When I song that I dislike comes on
- ☐ When I want more energy/motivation
- ☐ When starting/ending exercise
- ☐ Other times: ____

How often do you change the volume on your MP3 player? (check one)

- ☐ I am always changing the volume (100% of the time)
- ☐ Very often (80-90% of the time)
- ☐ Often (50-70% of the time)
- ☐ Sometimes (30-50% of the time)
- ☐ Occasionally (10-30% of the time)
- ☐ Almost never (less than 10% of the time)
- ☐ Never

APPENDIX 2: RAW LHQ DATA

Mean and standard deviations of responses to LHQ questions organized by HBM constructs. Indices include Cronbach's Alpha, a measure of internal consistency reliability for a scale variable. Responses ranged from one to seven, with greater numbers indicating agreement with the statement.

Question	Mean	SD	Alpha
Susceptibility to MIHL			
1. How susceptible to hearing loss do you feel?	3.05	1.41	
2. What is the chance that you will experience hearing loss from listening to loud music?	3.69	1.70	
3. How likely do you think it is that you will experience hearing loss resulting from listening to loud music on an MP3 player?	3.37	1.77	
4. Would you say that you are the type of person who is likely to experience hearing loss?	2.98	1.58	
Susceptibility to MIHL Index	3.27	1.37	0.862
Severity of MIHL			
1. How disruptive would hearing loss be to your quality of life?	6.29	1.07	
2. How disruptive would the cost of treating hearing loss be?	6.19	1.17	
3. How disruptive would it be to have to wear a hearing aid?	5.77	1.04	
4. How disruptive would hearing loss be to your ability to communicate with your friends and loved ones?	6.10	1.09	
5. How disruptive would it be to sustain permanent hearing loss as a result of listening to loud music?	6.33	0.81	
6. Overall, how disruptive would hearing loss be in your life?	6.40	0.66	
Severity of MIHL Index	6.18	0.67	0.759
Benefits of Preventing MIHL			
1. Making sure I listen to music at safe levels would prevent me from experiencing hearing loss.	5.34	1.66	
2. Turning my music down to a safe level when I'm in a quiet environment would be a good thing for me to do.	6.15	1.26	

3. Turning my music down to a safe level when I’m in a loud environment would be a good thing for me to do.	5.17	1.81	
4. Making sure my music is at a safe level when I’m in a quiet environment would prevent hearing loss.	5.65	1.37	
5. Making sure my music is at a safe level when I’m in a loud environment would prevent hearing loss.	5.33	1.52	
6. Setting my volume limiter at a safe level would be a good thing for me to do.	5.63	1.41	
7. Using special earphones that block out background noise when I listen to music would be a good thing for me to do.	5.40	1.56	
Benefits of Preventing MIHL Index	5.53	1.58	0.860
Barriers to Preventing MIHL			
1. If I turned my music down to a safe level in a loud environment, I wouldn’t be able to hear it.	5.10	1.51	
2. If I turned my music down to a safe level in a loud environment, I wouldn’t enjoy my music as much.	5.04	1.60	
3. I don’t know what level my music should be turned down to in a loud environment to protect my hearing.	5.30	1.63	
4. I don’t know what level my music should be turned down to in a quiet environment to protect my hearing.	4.63	1.97	
Barriers to Preventing MIHL Index	5.02	1.13	0.597
Self-Efficacy for Taking Preventative Action			
1. I feel confident in my ability to monitor the volume at which I listen to my music.	5.12	1.47	
2. I feel confident in my ability to make sure I listen to music at a safe level when I’m in a quiet environment.	5.23	1.55	
3. I feel confident in my ability to make sure I listen to music at a safe level when I’m in a loud environment.	4.61	1.39	
4. I feel confident in my ability to set the volume limiter of my MP3 player to a safe level.	4.67	1.93	
5. If I knew I were listening at an unsafe level, I would be willing to turn down the volume.	6.23	1.26	
Self-Efficacy for Taking Preventative Action Index	5.17	1.10	0.760

APPENDIX 3: CALIBRATION PROCEDURE FOR ER-200D DOSIMETER

1. Calibrate probe microphone.
    a. Place the probe tube into the calibration chamber, and recording the calibration tone (94 dB 1kHz tone).
    b. Calculate RMS of recorded tone in dB.
    c. Obtain scaling factor (dB) for recorded tone by subtracting recorded tone RMS (dB) from actual level (94 dB).
    d. Convert scaling factor (dB) to volts to use for all later scaling.
2. Place probe tube in ear canal, along with earphone.
3. Record a 10 mV, 1kHz tone in the ear canal (played through earphones).
    a. Calculate RMS of this tone, in volts.
4. Record a 10 mV, pink noise signal in ear canal (played through earphones).
    a. Calculate power spectrum density (periodogram) of this white noise.
    b. Calculate level of periodogram at 1kHz.
    c. Remove levels below 220 Hz, above 5000 Hz from periodogram (make equal to 1kHz).
5. Build a filter based on the modified periodogram.
    a. Scale by dividing filter by level at 1 kHz (from periodogram) to make filter gain at 1kHz equal to 0 dB.
6. View filter (using freqz) to ensure that the filter is appropriate as an ear canal resonance. If not, go to step 3 and re-record noise. Otherwise, continue.
    a. Flip this filter over by changing the signs of the filter coefficients for later use, if filtering out individual ear canal resonance is desired.

7. Create flat, 1 tap filter (filter gain = 1).
    a. Generate random noise.
    b. Pass generated noise through both the 1 tap flat filter and the filter generated in step 5 by the periodogram of noise measured in the ear canal. Measure RMS level of each signal.
    c. Calculate the ratio of difference between the two signals, convert to dB. This provides the amount of gain provided by the ear canal resonance in dB. This is the ear canal resonance gain.
8. Calculate RMS (in dB) of the measured 1kHz tone (from step 3). Subtract this level from the dosimeter's known calibration level for a 10 mV, 1kHz tone (94 dB is default). This is the dosimeter calibration gain.
    a. Subtract the ear canal resonance gain (step 7c) from the dosimeter calibration gain to obtain the total calibration factor.

For all recordings using the ER-200D Dosimeter input jack, add the calibration factor (a negative number) to the L_{eq} levels stored for every bin (3.75 minute). Ignore any pre-calculated averages provided by the ER-200D, as these are uncalibrated.