Critical Review: What is the effect of noisy listening environments on personal listening levels when using a personal listening device?

Neil Fine
M.Cl.Sc (AUD) Candidate
University of Western Ontario: School of Communication Sciences and Disorders

It has been hypothesized that personal listening devices (PLDs) could be causing risks to people's hearing. This critical review examines the effects of noisy listening environments on personal listening levels (PLLs) of people using PLDs. Study designs include: three within group repeated measures, and a single group study. Three studies looked at moderate background noises of approximately 70 dB A and found little risk associated, while one study used 80 dBA noise and found much more elevated PLLs. Further, when adding in headphones that physically attenuate sound there is a significant decrease in PLL in noisy environments and hence reducing risks. All studies agreed that with increased noise comes an increased PLL.

Introduction

For the purpose of this critical review, the definition of a PLD is any device that is used to play an audio signal that is coupled to a headphone device. Many people relate PLDs to iPods; however PLDs include various devices such as portable decks, and CD players.

A noise induced hearing loss (NIHL) is acquired by the intensity of noise, and length of time a person is exposed to noise working together (CASPLA). While moderate exposures to elevated signals may cause a temporary threshold shift to hearing, repeated exposures can progressively produce a permanent threshold shift. Common to both these types of NIHL are symptoms of tinnitus and difficulty understanding speech (CASLPA). Not only has considerable media attention been given to the potential of acquiring a NIHL with the use of PLDs (Fligor and Ives 2007), but hearing healthcare professionals, have expressed concern regarding the rise in use of PLDs, and it's potential effects on noise injury that could result in hearing loss (Williams, 2005). In the presence of background noise, we need to increase the intensity of a signal for it to be detected. Thus it has been hypothesized that when presented with background noise, a PLD user will increase their PLL causing a greater risk to acquiring a NIHL. Examples of these environments include public transportation, in public fitness clubs, street noise, or airplanes.

Noise standards exist all over the world with the purpose of reducing the risk of acquiring NIHL for the average person. While many studies in this review make reference to standards, in the end it is up to the user to operate a PLD at a safe level. The literature suggests that the type of earphone used when listening to PLDs can also influence listening level (Hodgetts et al. 2007; Fligor & Ives, 2007).Thus, PLL are affected by noise level and earphone style, combined with exposure time.

Objectives

The primary objective of this research is to critically evaluate existing literature of PLLs of PLD users in noise. The levels found in this literature will be assessed to see if risks are involved from PLD use. Outcomes of this review will allow for recommendations on safe PLD use.

Methods

Search Strategy

Computerized database including PubMed and MEDLINE were searched using the following search strategy: ((Personal Listening Devices) OR (earphones) OR (MP3)) AND ((environmental noise) OR (noise)) AND (Preferred Listening levels)) The search was then extended within PubMed by clicking on "Related Documents" when an appropriate article was determined. Articles were also chosen from a summary of information presented by Bill Hodgetts at the 2009 Canadian Academy of Audiology Conference titled "iPods and Hearing Loss: An Update." The search was limited to articles written in English. Additional articles were obtained through examining the reference lists of relevant journal articles.

Selection Criteria:

Studies selected for inclusion in this critical review assess the PLL from a PLD in a noisy situation. No limit was set on the number of noisy situations, the age of subjects, or type of device used.

Data Collection

A review of the literature yielded four single group studies, three of which used within group repeated measures.

Results

Within Groups Repeated Measures

Rice et al (1987) attempted to determine an estimation of hearing damage risk from personal cassette players. In this article the data was combined from two different studies to report listening levels and hours per week use. To date no study had combined an individual's listening levels to the hours of use they were exposed, thus fighting this previous limitation.

The first study conducted by Breslin includes 20 subjects that were tested in a laboratory and asked to adjust a calibrated personal cassette players (PCP) to a desired level in quiet and against a traffic noise background L_{Aeq} of 70 dB (equivalent continuous A-weighted sound pressure level). The differences seen here were small having users increase their desired level in quiet of 80.9 to 85.1 dB $L_{Aeq,}$ in noise. The second study carried out by Roper includes 41 subjects that were stopped on the street in a variety of noisy background environments and asked to participate. A sound level meter was used to measure the L_{Aeq} over a 2 minute period of their own PCP. Additionally, they were asked to adjust the volume of a pre-calibrated PCP and measurements were made in the same manner.

Due to the lack of difference in quiet and noise shown through statistical analysis in Berslin's study, his values were pooled with Roper's values in noise. "Two analyses were performed, the first relating to listening levels (L_{Aeq}) and the second to noise exposure measured in terms of equivalent daily listening levels averaged over a 40 hour week (L_{EX})" (Rice et al. 1987). Having L_{Aeq} values alone doesn't take into account the length of time users exposed, therefore not being able to make an estimation of damage risk involved. Converting the data to the L_{EX} allowed Rice et al (1987) to compare values against the normally accepted criteria for the estimation of noise-induced hearing loss (Robinson and Shipton, 1977).

For the purpose of this study, hearing disability occurs when the mean hearing level of 1, 2, and 3 kHz is equal to or greater than 30dB. When referring to Robinson and Shipton (1977), 30dB losses do not occur for noise emission levels below 100dB which is equivalent to an L_{EX} of 90dB over a 10 year period. Through mathematical calculation of the data, it was estimated that 0.065% of the PCP user population is at risk of obtaining a hearing disability (or 1 in 1538). This suggests that PCPs are not as much as a hazard as many perceive them to be.

It should be noted that the detailed calibration of their equipment involved a Knowles Electronic Manikin for Acoustic Research (KEMAR) which uses average real-ear-to-coupler difference (RECD) values. A limitation to this is that nobody is average and this could account for variation of the true data values obtained. Furthermore, in the laboratory data a 70 dBA traffic noise is not that loud, and even that small amount of noise showed a 4 dB increase, foreshadowing that further increases in environmental noise could cause larger changes and hence then making these values more risky. In these studies, there were no inclusion criteria of hearing thresholds that were mentioned to participate in the study (i.e. Normal thresholds). If a hearing loss was present, a person may have an increased PLL thus skewing the data. It may also be questioned why government standard to noise exposure were not used and compared against data from Robinson and Shipton (1977).

Single Group

The only study to date to collect real world data was conducted by Rice et al. (1987). The purpose of Williams (2005) study was to further this real world data on PLLs on PLDs in background noise.

Williams (2005) stopped 55 people on the street who were using their PLDs and recorded the equivalent continuous A-weighted noise exposure over a 2 minute time interval of the unchanged volume control($L_{Aeq,T}$). It should be noted that Williams (2005) used a similar experimental set up to Rice et al (1987). However, instead of using a pre-calibrated sound level meter (SLM) or pre-calibrated PLD, they used the KEMAR to take measurements on the street. Once stopped on the street, the earphones of the PLD were placed on KEMAR and the values were recorded. While the measurements were being made the subject was asked to fill out a questionnaire that included: hours per day of use; years of use; age; incidence of tinnitus; self-reported/ family expressed hearing loss; conversational difficulty in background noise; and occupation. Two sites were chosen to gather information in Australia where noise levels would be significant enough to have a change in volume. A-weighted equivalent continuous background noise levels were measured 3 times a day, for a total of 6 values which yielded an average of 73.2 dB A-weighted background noise.

The $L_{Aeq,T}$ measured under the headphones ranged from 73.7 dB to 110.2 dB with a mean value of 86.1 dB. With the mean background noise at 73 dB A, implying a signal to noise ratio of 13dB. The given listening times per day had mean value of 2.38 hours, and the number of years a PLD was used was 5.6 years. From the data collected, the eight-hour equivalent continuous A-weighted noise exposure ($L_{Aeq,\ 8h}$) was calculated.

The mean $L_{Aeq,\,8h}$ was 79.8 dB with a standard deviation of 9.0 dB. This conversion was done to make comparisons against the noise exposure figures used for workplace noise exposure regulations in common use around the globe (I-INCE: 1997).

The 79.8 dB $L_{Aeq,\,8h}$ was found to be well below the noise exposure level commonly set at the level of acceptable risk for workplace noise exposure (85 dB); but above the level considered to represent negligible risk (75 dB). Although the average was below, 25% of the population in this study was beyond levels deemed at-risk. Also, statistical analysis revealed that males showed a significant tendency toward greater noise exposure levels compared to females, 80.6 dB compared to 75.3dB respectively.

A limitation of this study was that a person chosen at random could have any type of hearing loss. By including people with hearing loss you could have increased PLL and thus skew your data. One participant actually had a high frequency hearing loss and wore his headphones over his in-the-ear (ITE) hearing instruments. Also, due to the small sample size any conclusions derived from this study is constrained to the populations that match the sample statistics. By using a KEMAR you are assuming each participant has average adult RECDs. Nobody is the average and by not measuring individual RECDs you do not know what level each person is actually exposed to.

Within Groups Repeated Measures

Fligor and Ives (2007) set out to estimate the number of people who are at risk for hearing loss from their portable music player headphones in different listening environments.

Fligor and Ives (2007) sampled one hundred normal doctoral students and asked them to listen to music from a list of songs through four different types of earphones. Two of the earphones (Sony MDR-EX51LP in-the-ear and the ER-6i in-the-ear) provided some degree of noise cancelation through their physical insertion, and the other two (Koss KSC11 over-the-ear and the Apple iPod earbud) provided no such attenuation. The students were placed in a soundproof booth. Different real-world sounds and artificial noise samples (ie. pink noise) were played through a speaker at different levels. Participants were asked to adjust the level of their music player to "where they liked it." These measurements were repeated for the different earphone type, noise type, and noise level in random order. The measurement of the PLL was measured in the ear with a probe tube attached to a real ear verification system. Mathematical corrections were made to the obtained values so they could use them to compare to government standards.

In quiet, the students listened to the music at the same level across all the different earphone types. It can be noted that on average males chose a level of 5dB higher than females in this condition. When an 80dBA background airplane noise was introduced, a significant difference in preferred listening levels was noted across earphone type: ER6i= 78 dB, Sony earbud = 84 dB, Koss= 89dB, and iPod earbud = 89 dB. The attenuation values provided by each earphone were as follows: ER6i= 25 dB, Sony earbud = 9 dB, Koss= 2dB, and iPod earbud = 1 dB.

These data were analyzed by a nonlinear regression model to determine if the amount of sound isolation affected listening behaviors, and if this effect on behavior could be quantified. The outcome revealed background noise did affect preferred listening levels and people who listened risky levels in quiet increased it to riskier levels in the presence of noise. While statistical analyses were not shown, the gaps between quiet and noise are evident. This risky behaviour was more evident with earphones that did not attenuate any sounds were used. The amount of sound isolation by the earphones in noise listening environments allowed subjects to choose PLLs that were lower.

"If a chosen listening level of 85 dBA is deemed the cut-off constituting 'risky' behaviour, then roughly 6% of subjects listening in a *quiet* setting are 'risky listeners'"(Fligor and Ives, 2007). When the subjects were subjected to the airplane noise, 80% of them exceeded the 85 dBA who were using the iPod and Koss earphones. When using the ER-6i, only 20% exceeded 85 dBA.

In this study it was not mentioned if all the different songs were spectrally the same which could influence the level the user would need to adjust to obtain their PLL. Another limitation of this study is equations used to convert ear canal values to compare against government standards were not given. Additionally, the time spent listening to these levels is needed to predict estimation of risk of damage and no attempts to obtain these values were carried out in this study. Lastly, this was an unpublished manuscript and while significances were stated for some comparisons, the analyses were not shown.

Within Groups Repeated Measures

Hodgetts et al (2007) set out to determine the influence of listening environment and earphone style PLLs measured in the user's ear canal. A secondary objective was to use the measured PLLs to determine the permissible listening duration to reach 100% daily dose.

Thirty-eight subjects participated in this study (15 males and, 23 females with a mean age of 27.5 year old). Participants were recruited from the Faculty of Rehabilitation Medicine at the University of Alberta. All subjects were screened and had pure tone hearing levels better than 20 dB HL at 500, 1000, 2000, and 4000 Hz. There were two independent variables in this study. The first, *headphone style*, had three levels: Earbud, over-the-ear (OTE), and over-the-ear with noise reduction (NR) (the same headphones with a noise reduction circuit). The second, *environment*, also had three levels: quiet, street noise and multi-talker babble. The dependent variable was ear canal A-weighted sound pressure level. The quiet condition was used as a baseline measurement to compare to the noise conditions. The noise was played from a speaker 1 meter away from the subject at zero degrees azimuth. The street noise was a 10 second repeating pattern with an intensity that varied from 70-80 dB A. The multi-talker babble was presented at a level of 70 dBA. A 3 x 3 within-subjects repeated-measures ANOVA was used to analyze the data. For all nine conditions, a probe microphone was inserted into the user's left ear to determine the real ear measurement at the eardrum. The probe microphone was connected to an Audioscan Verifit (a real ear measurement and verification system). While the Verifit is primarily used for hearing aids, in this experiment the probe tube attached to it was used just for the purpose of measuring sound at the eardrum.

Findings suggest a significant effect for both headphone style and environmental factors. "When collapsed across all environments, use of the in-the-ear headphones resulted in significantly higher PLLs (M = 84.4) compared to the over-the-ear (M =80.9) and the over-the-ear with NR (M = 79.9). When collapsed across all headphone styles, the street noise (M = 85.4) resulted in significantly higher PLLs than either the multitalker babble (M = 83.7) or the quiet condition (M = 76.0)" (Hodgetts et al, 2007). However, some comparison results did not yield significant differences: The earbuds versus OTE in quiet, OTE versus OTE with NR in quiet, and the OTE versus OTE with NR in street noise and multi-talker babble.

Using the following equation: $T\ (\text{min}) = 480/2^{(L-85)/3}$, Hodgetts et al (2007) used the mean PLLs from the nine conditions to calculate the listening duration to reach 100% daily dose. The top 3 conditions with the quickest time to reach 100% daily dose were the earbud in street noise (3.30 hours), the earbud with multi-talker babble (5.45 hours), and the OTE in street noise (9.06hours). All other conditions were 12 hours and above with the OTE +NR in quiet yielding 77.74 hours. In general, the PPLs chosen by the subjects in this experiment shows that MP3 use is not as significant as a concern that is noted by the mainstream media (Hodgetts et al, 2007).

A few limitations of this study need to be noted. The formula used to calculate the 100% daily dose assumes occupational noise which is more predictable in spectral and temporal properties than music. It could be argued that these results may only extend to pop music with a consistent level. Next, damage risk criteria are based on sound levels in the free field and this experiment used probe tubes to measure it in the ear canal. The ear canal would give an increase to the incoming sounds giving the dBA weighted values a slight positive bias, thus the these values should be lowered a few dB if they are to be used in the calculations. Lastly, the levels chosen by the subjects were quite conservative, and this could be because it was obvious what was being tested and the experimenter might not want to alarm the audiologist.

Discussion

A limitation across these studies is the consistency exhibited in regards to how levels are measured (KEMAR or probe tube), and the manipulations made once measured. While one study used a L_{EX} 40 hour week, one used an 8 hour equivalent, one used time to daily dose, and the other used nothing but the level. Also with regards to consistency, levels must be compared to the same standard or a close equivalent. Two studies used a government standard, one used Robinson and Shipton (1977), and the other used workplace noise exposure regulations in common use around the globe (I-INCE: 1997).

After critical evaluation of the studies presented, a significant level of evidence was present in each study. Despite the limitations, they were not great enough to question the consistent outcome. All of the studies agreed that with increased noise comes an increased PLL with PLDs. However, three of the studies concluded that the noisy environments did not cause a significant change to the PLL, that concern should be warranted regarding risk of a NIHL. The one study that differed was the study conducted by Fligor and Ives (2007). Their studied showed that 80% of their participants were at risk when using earbuds, and still 20% were at risk with Er6i in the noisy situations by deeming 85 dBA as a risky level. This one study differs from the others significantly by it being the only one that used 80 dBA noise, instead of something closer to 70 dBA like the rest, and it did not take time into account.

Fligor & Ives (2007) and Hodgetts et al. (2007) examined multiple headphone styles and agreed that style has an effect on PLL. Particularly, the earbud style in both studies resulted in users choosing a higher PLL in the same noise condition.

Regardless of manipulations to data, or headphone style, the findings across the reviewed studies agreed that with increased noise comes the effect of an increased PLL. For the studies that subjected patients to environments with noisy conditions close to 70dBA, PLL were not a concern for the average population (Hodgetts et al. 2007, Williams, 2005, Rice et al. 1987). Fligor and Ives (2007) study presented an 80dBA noise that showed a more significant risk to hearing loss especially with earbud style headphones. In their study when comparing PLLs across headphone styles, all of them increased approximately 10dB when an 80dBA noise was used over a 70dBA noise.

Recommendations

It is unanimous across studies that the environment you are in influences your PLL, and hence influences your risk to hearing loss. Extra caution should be employed when choosing a PLL in noisy environments. Additionally, through review of the research it was found that the headphone style can have a significant effect on attenuating sound. It was agreed between Fligor & Ives (2007), and Hodgetts et al. (2007) that the earbud style gave the least attenuation and loudest PLL. It can be shown through these studies that physically attenuating sound is the best option when choosing noise canceling headphones.

From these findings it can be suggested to choose a PLL in a quiet environment before entering a noisy one. Regardless of headphone style, in quiet environments PLLs are all similar. By choosing a PLL in the quiet environment and sticking to it, you are protecting yourself from a higher and possibly damaging PLL in the noisy environments. This is especially useful for the earbud style headphones.

Recommendations for future research

Future researchers need to agree on a standard when measuring PLL. As technology has advanced, more accurate ways of measuring sounds perceived by humans have developed such as probe microphones that measure at the eardrum. Still, researchers are using KEMAR. Additionally, what data is compared against needs to be consistent when drawing conclusions of risk criteria within a study. Lastly, the current risk criteria that exist use levels that are measured outside of the ear. Perhaps where we are now with probe tubes that allow us to measure at the eardrum,, that new standards should exist with this type of measurement.

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