Listening levels of teenage iPod users: does measurement approach matter?

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Abstract

The main objective of this study was to determine the influence of background noise levels and measurement approach on user-selected listening levels (USLLs) chosen by teenaged MP3 player users. It was hypothesized that the presence of background noise would (i) increase the USLL across all measurement approaches, (ii) result in no significant USLL differences between survey reports, objective lab measures or calibrated self-report field measures, and (iii) cause no interaction effect between level of background noise and measurement approach. There were two independent variables in this study: the level of background noise and measurement approach. The first independent variable, level of background noise, had two levels: quiet and transportation noise. The second independent variable, measurement approach, had three levels: survey, objective in-ear lab measurement and calibrated self-report field measurement. The dependent variable was ear canal A-weighted sound pressure level (dBA SPL). A 2 x 3 repeated-measures ANOVA was used to determine the significance of the main and interaction effects. USLLs increased in the presence of background noise, regardless of the measurement approach used. However, the listening levels estimated by the participants using the survey and self-report field measure were significantly lower than those recorded using in-ear laboratory measurements by 9.6 and 3.3 dBA respectively. In-ear laboratory measures yielded the highest listening levels. Higher listening levels were observed in the presence of background noise for all measurement approaches. It appears that subjects' survey responses underestimate true listening levels in comparison to self-report calibrated field measures, and that both underestimate listening levels measured in the laboratory setting. More research in this area is warranted to determine whether measurement techniques can be refined and adjusted to accurately reflect real-world listening preferences.

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Introduction

As evidenced by recent publications,[1-9] there is ongoing interest in examining the effects of exposure related to personal listening device (PLD) use on hearing. It is well established that available PLDs are capable of outputting potentially harmful listening levels[10] and that some percentage of the population of listeners will be at risk for hearing loss based on their estimated daily noise dose.[11] A report for the European Commission warns that approximately 5-10% of young listeners are at risk of developing permanent noise-induced hearing loss (NIHL) from PLD use.[12] Consequently, as discussions continue regarding the actual degree of risk and the number of people potentially affected by PLD use, research must now focus on isolating the subset of listeners identified as being at risk, and critically evaluate the measures used in this risk assessment.

Exposure and risk levels related to PLD use have typically been calculated using occupational noise standards.[13,14] While some authors have cautioned that these comparisons may not be optimal,[7,9] the European Commission Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) has suggested that workplace noise regulations may be applied to leisure noise exposure, including PLD use.[12]

Much of the research in this area has relied on objective in-ear sound pressure level (SPL) measurements or survey data to collect subjective or self-report information from large participant groups. Comparison of standard measurement protocols has occurred;[9] however, there has been limited evaluation as to whether survey and in-ear measurements yield comparable listening levels, or which method records the most accurate listening level used outside of the laboratory environment. As Fallah and Pichora-Fuller[15] highlighted, *even if people are informed about hazardous levels in terms of numerical decibel levels descriptions, they may not be able to relate decibel levels to their everyday experience* (p.66). This may directly affect an individuals' ability to accurately assess and critically report his or her listening levels using perceptual scales of loudness. Significant discrepancies have been found between in-ear objective measures and subjective listening estimations.[5,16]

Conversely, the influence of testing in an artificial laboratory setting with a probe microphone in the ear canal requires further discussion. How closely do user selected listening levels (USLLs) derived in the laboratory reflect the *real world* listening levels of participants? Is there an experimenter bias or *white-coat* effect that may be influencing the USLLs? And if so, can this effect be quantified?

One way to examine this possibility is to compare USLLs in three different scenarios: i) laboratory probe microphone testing in simulated conditions, ii) field testing in the *real world* environments with a calibrated PLD, and iii) self-report measures. Determining the magnitude of the laboratory effect and the ability of subjects to accurately report self-listening levels is important to validate available measurement techniques.

In addition, the majority of research examining USLLs and PLD listening patterns has been conducted with adult populations. This investigation focuses on evaluating several different measurement techniques, frequently used in auditory risk assessments, while measuring the preferred listening levels of teenage PLD users. This study specifically seeks to determine if possible discrepancies exist between survey and laboratory data and between measurements taken in the field and measurements taken in the laboratory. The following research questions were considered: i) Is there a main effect of background noise level (quiet, transportation noise) on USLLs in teenage PLD users? ii) Is there a main effect of measurement approach (survey, in-ear laboratory, self-report field measure) on USLLs in teenage PLD users? iii) Is there an interaction between measurement approach and background noise level on USLLs?

Materials and Methods

Subjects

A total of 19 teenaged students participated in the study: 13 females and 6 males. Ages ranged from 12 to 18 years with a mean age of 14.7 years. All student participants were PLD users and rode public transit to and/or from school. Users were also defined as those who utilized a PLD for a minimum of 30 min a day for 3 or more days a week. All subjects passed a hearing screening at 20 dB HL at 0.5, 1, 2 and 4 kHz. No compensation was provided and all subjects provided informed consent and informed parental consent. Subjects were recruited through the University of Alberta Faculty of Rehabilitation Medicine, a local hospital, and a local junior high school. This study was approved by the Health Research Ethics Board (HREB) at the University of Alberta.

Acoustic signal and instrumentation

Three iPod™ Nanos (Apple, USA) with stock iPod white earbud headphones, all verified to have the same output characteristics, were used. The default equalizer settings were used on all devices. Subjects were asked to choose one of the top 10 downloaded songs from iTunes at the time of the study and this same song was used for each section of the study. Each song was analyzed following the procedures outlined by Hodgetts *et al*.[4] Specifically, the dynamic range and frequency spectrum were considered. A small dynamic range and relatively consistent frequency spectrum allowed participants to set a listening level appropriate for the duration of the track without the need to make multiple adjustments due to intensity and/or frequency variations in the song. Similar dynamic ranges and spectra between the songs also allows for USLL comparison across subjects, regardless of the acoustic signal used. The intent behind providing subjects some choice over the music used for measurement was that they would select a song they enjoyed listening to, thereby encouraging them to select listening levels representative of their usual behaviour (similar to the rationale employed by Worthington *et al.*[9]). No artificial maximum output limit was implemented on the device during the testing and data collection process; this setting was left in the manufacturer's default mode.

Transportation noise was recorded for use during the objective in-ear measurement section. The transportation noise was recorded (.wav file at 44.1 KHz) using an m-audio portable recording device (m-track recorder; M-Audio, Quebec City, Quebec, Canada). To obtain a representative measure of the background noise level, several sound recordings and simultaneous SPL measurements were made using a Larson Davies Sound Level Meter (Larson Davies, Depew, New York, USA) while riding on an Edmonton Transit System public bus frequented by students at a time of high student occupancy (before and after school). The sound level meter was used for 5-min segments on 10 occasions and set to measure in slow-response mode to derive the average A-weighted equivalent continuous sound pressure level for this transportation scenario. We chose one noise track recording that contained elements of bus engine noise, traffic noise and multi-talker babble as representative of the average. The average A-weighted equivalent continuous sound pressure level measured was 75 dB; therefore, when we presented the actual recorded noise track to subjects it was at a calibrated level of 75 dBA.

Calibration of ear canal sound pressure level to volume dial

To assess the linearity of the volume dial on the Apple iPod, the input-output relationship from the volume control was measured. A scale indicating percentage values in increments of 10 from 0 to 100 was fixed to the display screen of the iPod (Figure 1). The ear canal SPL was measured in each of the examiners' ears when the iPod was set to 25%, 50%, 75% and 100% of full volume (see below for details on in-the ear measures; see Figure 2). For each participant in the study, ear canal SPL was measured only at 25%, 50% and 75% of full volume. This provided a dial setting to ear canal SPL transform that could be used to evaluate both survey data and field measures taken by participants, as well as for the calculation of noise exposure estimates. These measurements were taken in the absence of background noise in order to record in-ear intensity levels of the device only. This was to ensure that the dial to ear canal SPL transform for each subject reflected the device output only without potential inconsistencies introduced by background noise. We verified whether this would be an issue on five subjects. We found that as long as the volume bar was at least at 50% of the maximum setting, the presence or absence of background noise had no effect on the USLLs. Measurements at 100% were not made with participants (only the examiners in the linearity test) to prevent exposure to unnecessarily high noise levels.

Figure 1. Image of the scale indicating percentage values in increments of 10 from 0 to 100 that was fixed to the display screen of the iPod. The value represents the volume bar setting, not the actual sound pressure level output level.

Measurement type

USLL data were collected using three measurement approaches: a survey, objective in-ear laboratory measures, and self-report field measurement. The survey included some questions regarding each participant's listening habits and attempted to document their personal impressions regarding their listening habits. However, the primary question of interest from the survey was for subjects to imagine themselves in a quiet environment (*e.g.*, a library) or a noisy environment (*e.g.,* riding a bus) and to estimate their listening level using a numerical value, where 0 was equivalent to no volume, and 100 was equivalent to the loudest possible volume (survey attached as Appendix). The in-ear measurements were made using a probe microphone as described below. To complete the self-report field measure portion of the study, each participant was provided with an iPod Nano, earbud headphones and response sheet for a period of 4 days. Each iPod contained the top 10 downloaded songs from iTunes when the study was run and had the same volume scale indicating percentage values in increments of 10 used in the calibration procedure. Participants were instructed to set the volume to the level at which they would normally listen. Each participant was asked to make four measurements a day (two in quiet, and two while riding the bus) using the same song used for the laboratory measurements, and to record their USLL using the percentage scale while riding the bus and in a quiet environment. The survey measures of USLLs were the first collected for all subjects, as it was also the screening tool for subject recruitment. The order of the in-ear measurements and the self-report field measures was then randomized across subjects.

Background noise levels

Across all measurement conditions, USLLs were considered in two listening conditions: in quiet and in the presence of transportation noise. These conditions were detailed in two separate questions on the survey (questions 6 and 15) and recreated for the in-ear measurements. To simulate realistic listening conditions, in-ear measurements occurred in a quiet room with background noise levels of 32 dBA (+/- 3 dB). Pre-recorded transportation noise was presented at 75 dBA, the intensity level representative of that listening environment, in the method described below. For the self-report field measures, subjects were directed to make measurements while riding to or from school on the bus and in a quiet environment, and to document their location at the time of measurement. This allowed researchers to confirm that measurements made on the bus corresponded with times of high student occupancy, when background noise levels would be similar to those measured by the researchers.

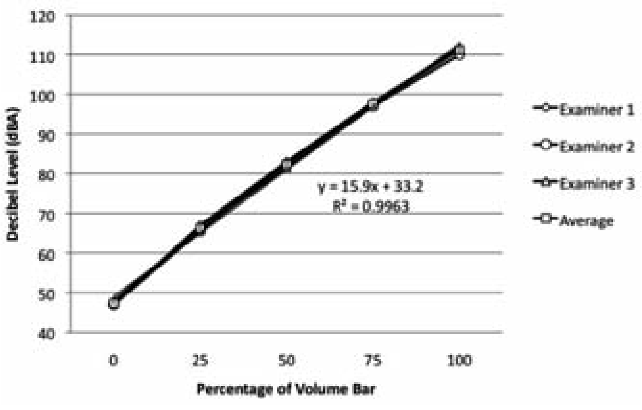

Figure 2. Input (x-axis)-output (y-axis) relationship of the volume control of the iPod. Ear canal A-weighted sound pressure level (dBA) measured in examiners' ears at 25%, 50%, 75% and 100% of full volume. Equation shown represents linear trend line used to convert percentage values taken from the volume bar into sound pressure level values. Similar calibration trends were derived for each subject in the study.

Measurement of ear canal sound pressure level

In the laboratory measurement condition, USLLs were recorded as the SPL in the ear canal. A probe microphone was placed in each subject's left ear in order to measure the user-selected SPL in each listening condition (quiet and transportation noise). Otoscopy was performed to ensure that the probe tip was within 5 mm of the tympanic membrane. To avoid disturbing the microphone, the earbud was carefully placed in the subject's ear by the examiner, with comfort confirmed by the participant. The subjects inserted the right headphone into their own ears. Participants were then asked to set the volume to the level they most preferred. Once the level was set, the SPL measurement was completed using a real-time signal analyzer (Audioscan Verifit, Dorchester, Ontario) that averaged the level over a 15 s period of the song. The SPL values from the Verifit were exported and converted to A-weighted values by applying an A-weighting transfer function.

The order of presentation of the background noise conditions (quiet and transportation noise) was randomized. Subjects were seated with a speaker positioned one meter away at zero degrees azimuth. In the noise condition, the pre-recorded transportation noise was played through this speaker at zero degrees azimuth and one 1 meter from the subject's ear at the intensity level representative of that listening environment. To ensure that 75 dBA SPL was being delivered in the acoustic environment under test, one of the experimenters was seated in the situation that each subject would be placed in and the sound level meter was placed at the experimenter's entrance to her ear canal. The level of the background noise was adjusted to ensure that the slow-response average equivalent A-weighted SPL was 75 dB. In each listening condition, participants were instructed to set the volume on the iPod to their USLL while listening to their selected song. The ear canal SPL was also measured at volume settings of 25%, 50% and 75% on the iPod for all subjects using the method described above.

The survey and self-report data collection methods both yielded values reflecting a percentage of maximum volume. The sixteen USLLs obtained through self-report (eight in quiet, eight in the presence of transportation noise) were averaged to provide a mean listening level for each individual in each listening condition. Percentages from both measurement conditions were converted into approximate decibel levels using the dial setting to ear canal SPL transform created during the calibration procedure specific to that subject. The in-the-ear measurements at 25%, 50% and 75% of the volume bar were used to develop a linear equation for each participant, which was then used to convert the percentage of the volume dial recorded into a dBA value. dBA values were used to compare listening levels across all conditions.

To compare the findings from this sample to existing reports, and to facilitate discussion surrounding the differences in listening habits between teenagers and adults, the estimated allowable time of exposure in a day was calculated using the USLL values measured in-ear using the following equation: $T = 480/2^{((L-85)/3)}$, where 480 = number of min in 8 h, L = MP3 player average output level, 85 = maximum level in an 8-h time period, 3 = the exchange rate (trading ratio).[4,13]

Results

A 2×3 repeated-measures ANOVA assessing the effect of listening environment and measurement approach was performed using SPSS (Version 14, 2005). The first independent variable was Level of Background Noise with two levels (Quiet, Transportation Noise). The second independent variable was Measurement Type with three levels (Survey, Self-report, and Laboratory). The ANOVA revealed no significant interaction effect between the two independent variables. Therefore only the main effects were explored.

Mean USLLs for each condition are displayed in Figure 3. Main effects of background noise level ($F_{(1,18)} = 51.788$, P<0.001; eta squared = 0.742) and measurement type ($F_{(1.392,25.052)} = 11.775$, P=0.001; eta squared = 0.395) were significant. Mauchly's test of sphericity was violated, therefore sphericity was not assumed and the Greenhouse-Geisser statistic was used. When collapsed across all measurement types, the presence of background noise (M=83.5 dBA, 95% CI= 80.4 to 86.6 dBA) resulted in significantly higher USLL than the absence of background noise (M=70.3 dBA, 95% CI= 66.7 to 73.9 dBA) (t(56)= -7.892, P<0.001, two-tailed), effect size 0.58. When collapsed across level of background noise, the biggest difference in USLLs were between the survey (M=71.6 dBA, 95% CI=67.5 to 75.7 dBA) and the in-ear laboratory method (M=81.2 dBA, 95% CI=77.9 to 84.5 dBA), effect size 0.67. Self-report field measures (M=77.9 dBA, 95% CI= 74.4 to 81.3 dBA) were also significantly lower than the in-ear laboratory method. However, the effect size associated with this difference was quite small (0.04). We also assessed individuals on a case-by case basis to determine whether or not their USLL exceeded 85 dBA. In quiet listening settings, 21% of subjects (n=4) listened at volume levels exceeding 85 dBA as measured using both in the ear and self-report field measures; only 5 % (n=1) exceeded 85 dBA using survey measurements. The number of subjects listening at or above 85 dBA in the presence of background noise grew to 57% (n=11) using in-ear measurements, 47% (n=9) using self-report field measurements, and 36% (n=7) using survey measurements. Safe listening periods would change in length if the survey, self-report or in-ear listening levels were used.

Discussion and implications

Overall, we found significant differences in USLLs depending on what measurement approach was used. The laboratory measures yielded the highest estimates and the survey approach yielded the lowest. With respect to the influence of environmental noise, a similar pattern of results emerged in this study as has been reported by others in the literature.[4,5,17] Regardless of measurement type (survey, self-report or in-ear laboratory), USLLs for this group of teenage listeners was higher in background noise than in quiet. It is interesting to note that on average, mean USLLs were fairly conservative. This has been reported elsewhere in the literature.[4,15] One thing that is also clear from most of the research in this area is that individual differences in USLL tend to be fairly large. Mean USLLs might give a false sense of ease with PLD listening levels because the *soft* listeners and the *loud* listeners tend to cancel each other out. In this study, that seems to be the case. Other researchers have found that between 25% and 33% of adults in a given study may be considered *at risk* users.[11,15] We found that approximately 50% of our subjects listened at levels in background noise that, if they were to choose those levels routinely, may impact their hearing. Some subjects even listened to potentially hazardous levels in quiet. In contrast to this finding, some subjects choose levels that are quite conservative and would allow them to listen to the PLD for a near indefinite period of time (or at least long past the battery life of the device). However, as Hodgetts *et al.*[4] point out, the method of measurement (ear canal SPL) does not account for the transfer function to the free field. Additionally, the measurement tool used, the Verifit, only has a measurement pass band from 200 to 8000 Hz. It is possible that the A-weighted SPL over the entire audible range (*e.g.*, 20 to 20,000 Hz) might result in a slightly different value from those obtained with the limited pass band of the Verifit. Overall, it is likely that 50% is too high an estimate because the ear canal SPL will be greater than the assumptions of SPL entering the ear in the free field. One needs to be slightly cautious in ver interpreting this number; however, the primary objective of this study was to address the issue of measurement method, not to determine the percentage of teenagers at risk.

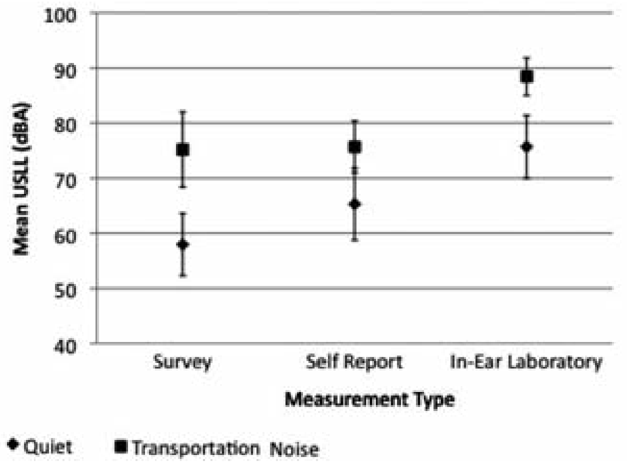

Figure 3. Mean user-selected listening levels for each level of background noise across each measurement type. Significant main effects for level of background noise and measurement type were found. No significant interaction effect between the two independent variables was measured.

USLLs, as measured through self-report field measurements, were lower than in-ear laboratory measurements. Several possible explanations are offered for this observed phenomenon. First, subjects were asked to record listening levels over a period of four days and these data were averaged for each subject. In contrast, in-ear measurements were based on a single trial. Naturally, environmental noise will vary considerably more in the field, thereby conditioning the listener to choose different USLLs. The laboratory setup, on the other hand, is much more constrained and constant. It is also possible that additional variables, such as mood or activity, may contribute to variability in USLLs in the field that are not captured in the one-time laboratory measurement. Considerable variability was also observed within each subject's reported USLL in both quiet and noise conditions. Finally, the difference in USLL may be explained by the goal or the motive of the listener. While in the lab, the participant was sitting and focused on listening to the PLD, they were not attempting to complete any other task simultaneously. Comparatively, while taking self-report field measurements, individuals were listening and making USLL measurements while attending to other tasks, such as watching for their bus stop, interacting with friends, studying or reading. Similarly, the survey questions specified both an environment and an activity. All of these tasks involve a shift in focus away from the music to an alternative activity; potentially resulting in a lower USLL than when focused listening occurs.

Conclusions

This study addressed the question of whether different measurement approaches yield different estimates of USLLs with PLDs. By calibrating the iPod to each individual's ear, it allowed us to compare USLLs across approaches using one metric (ear canal A-weighted dB SPL). There remain some limitations with each approach. It would appear that simply asking users to estimate how loud they listen via a survey underestimates true listening levels. Calibrated field measures hold promise, but characterizing moment-to-moment and longer-term exposure is difficult. Future research focusing on controlling variables in self-report measurement techniques is needed. The development of a tracking tool (perhaps an iPhone/iPod Touch App) that can measure in real time the daily noise exposure and log it within the application may be the most effective way to objectively record listening duration and exposure levels, although special headphones and microphones would need to be used in order to do this. The laboratory measures could be strengthened by repeated in-ear measurements across several sessions in order to better understand the variability in USLL for a single subject. If these measures were then compared to a field-logging real-life exposure, we would have a better understanding of the accuracy of the laboratory measurement techniques used.

More research in this area is warranted to determine whether measurement techniques can be refined and adjusted to accurately reflect real-world listening preferences. This study offers a new evaluation approach using self-report field data in which listeners were explicitly taught to keep a record of listening behaviors. This offered researchers a strategy for monitoring listening behaviors across time, and may be an effective way of more closely tracking a sample and evaluating participants' use patterns based on real-world data. Inclusion of this type of data collection may prove useful in future research.

References

1. Levey S, Levey T, Fligor B. Noise exposure estimates of urban MP3 player users. J Speech Lang Hear R 2011;54:263-77.
2. Kumar A, Matthew K, Alexander SA, Kiran C. Output sound pressure levels of personal music systems and their effect on hearing. Noise Health 2009;11:132-40.
3. Torre P 3rd. Young adults' use and output level settings of personal music systems. Ear Hear 2008;29:791–9.
4. Hodgetts WE, Rieger JM, Szarko RA. The effects of listening environment and earphone style on preferred listening levels of normal hearing adults using an MP3 player. Ear Hear 2007;28:290-7.
5. Hodgetts W, Rieger J, Szarko R. What is the influence of background noise and exercise on the listening levels of iPod users? Int J Audiol 2009;48:825-32.
6. Morata TC. Young people: their noise and music exposures and the risk of hearing loss. Int J Audiol 2007;46:111-2.
7. Fligor BJ. "Portable" music and its risk to hearing health. Hear Rev 2006;13:68-72.
8. Zogby International. Survey of teens and adults about the use of personal electronic devices and head phones. Zogby International; 2006. http://www.asha.org/uploadedFiles/about/news/atitbtot/zogby_survey2006.pdf#search=%22zogby%22 Accessed: September 14, 2007.
9. Worthington DA, Siegel JH, Wilber LA, Faber BM, Dunckley KT, Garstecki DC, et al. Comparing two methods to measure preferred listening levels of personal listening devices. J Acoust Soc Am 2009;125:3733-41.
10. Fligor BJ, Cox LC. Output levels of commercially available portable compact disc players and the potential risk to hearing. Ear Hear 2004;25:513-27.
11. Williams W. Noise exposure levels from personal stereo use. Int J Audiol 2005;44:231-6.
12. Scientific Committee on Emerging and Newly Identified Health Risks, 2008. Potential health risks of exposure to noise from personal music players and mobile phones including a music playing function – Preliminary report. Brussels: European Commission, Health & Consumer Protection; 2008. Available from: http://ec.europa.eu/health/scientific_committees/consultations/public_consultations/scenihr_cons_08_en.htm
13. National Institute for Occupation Safety and Health (NIOSH). Criteria for a recommended standard: occupational noise exposure, revised criteria. Cincinnati: NIOSH; 1998 Pub. No. 98-126.
14. Occupational Safety and Health Administration. Occupation noise exposure: Hearing conservation amendment; Final rule. Federal Register. 1983;48:9738-9785.
15. Fallah S, Pichora-Fuller K. An acoustical study of iPod use by university students in quiet and noisy situations. Can Acoust 2006;34:66-7.
16. Ahmed S, Fallah S, Garrido B, Gross A, King M, Morrish T, et al. Use Of Portable Audio Devices By University Students. Can Acoust 2007;35:35-54.
17. Portnuff C, Fligor B. Sound output levels of the iPod and other MP3 players: is there potential risk to hearing? Cincinnati, OH: NIHL in Children Meeting; 2006. https://www.hearingconservation.org/docs/virtualPressRoom/portnuff.htm Accessed: November 20, 2007.