Investigation of the Sound Pressure Level (SPL) of earphones during music listening with the use of physical ear canal models

K P Aying¹, R E Otadoy and R Violanda

Theoretical and Computational Sciences and Engineering Group
Department of Physics, University of San Carlos, Nasipit, Talamban, Cebu City, Philippines

E-mail: ayingismylastname@gmail.com, r_otadoy@yahoo.com, renante.violanda@gmail.com

Abstract. This study investigates on the sound pressure level (SPL) of insert-type earphones that are commonly used for music listening of the general populace. Measurements of SPL from earphones of different respondents were measured by plugging the earphone to a physical ear canal model. Durations of the earphone used for music listening were also gathered through short interviews. Results show that 21% of the respondents exceed the standard loudness/duration relation recommended by the World Health Organization (WHO).

1. Introduction
With the advent of affordable and mobile music players, listening to music has become one of the favorite past time of the general population today. With this personalized technology, earphones are massively used and have become a part of everyday activity. While music listening using earphone has become a stress-relieving activity, the effect of excessive loud music listening is often ignored or even unheard of. Though some of the music player issue some warning prior to increasing the volumes very little is known about the actual sound pressure level (SPL) produced inside the auditory canal. Excessive loudness is one of the causes of hearing loss in the world today [1,2]. In fact, the World Health Organization (WHO) already issued a set of standard for the amount of noise exposure level every day for a safe listening [1].

This study measured the sound pressure level used by a representative sample of the general populace in their music listening activity using a physical ear canal model. The duration of the music listening per respondent was also determined through interview. The measured SPL and duration was elucidated in comparison with the issued standard set by WHO.

2. Physical ear canal (PEC) model
The sophistication and complexity necessary to measure SPL in an actual ear canal cannot be address with the current laboratory set-up. Instead of measuring the SPL in an actual ear canal, this study

¹ To whom any correspondence should be addressed.
utilizes a physical ear canal model (PEC) in the measurement. The PEC is a hollow cylindrical tube made of engineering plastic and steel. The PEC has an inner diameter of 8.00 mm which is comparable to the average diameter of the human ear [3-5]. Three different lengths of (29.80±0.05)mm, (29.00±0.05)mm, and (26.50±0.05)mm were utilized to include the range of ear canal length reported by the literatures [4,5]. Figure 1 shows the schematic diagram of the PEC. The earphones to be tested are placed at one end of the PEC while the sound meter is placed on the other end.

[Figure 1. Schematic diagram of a PEC model. The dimensions of the PEC models were obtained from two renowned medical literatures [4,5].]

3. Characterizing of PEC models
Prior to using the PEC in the SPL measurements, it is very important to study the acoustical property of the PEC and compare it with the acoustical property of the actual ear canal. Here, only the frequency response property is considered as the actual ear canal acts as a band pass filter of the sound entering the auditory system [6-8]. To determine the frequency response of the PEC, a white noise sound was generated by a LabVIEW computer program using the sound card of the computer and fed it to an earphone which was inserted to one end of the PEC. The sound generated by the earphones was captured by placing a Brüel&Kjær Pre-polarized Free-field ½” Microphone Type 4189 at the other end of the PEC. The microphone was coupled to NI-USB 4431 Data Acquisition module which is connected to the same computer. The power spectrum of the captured sound was then computed using a LabVIEW code that performs a Fast Fourier transformation. A normalization process was then applied to the calculated power spectrum to correct for the distortion of the white noise caused by the earphone itself. Figure 2 shows the experimental setup for the characterization of the PEC.

[Figure 2. Schematic diagram of experimental setup where a) computer running with LabVIEW program and MATLAB 7.1 software, b) NI DAQ module, c) earphone, d) PEC models, e) Brüel&Kjær Prepolarized Free-field ½” Microphone Type 4189.]
4. Measuring of sound pressure level with earphones
Sound pressure levels (SPL) were measured for random respondents. The selection of the respondents were done by asking the respondents that were listening to music using earphones that are present in a particular environment such as, university campuses, inside a public transportation vehicle, shopping malls, on the sides of the road and etc. The respondents have ages ranging from 16 to 35 years old with almost the same number of males and females. During each measurement, the respondents were asked to set the volume of their music players to the usual volumes that they used in listening. Their earphones are then inserted to one end of the PEC and a PYLE® PSPL05R Sound Level Meter is inserted in the other end to measure the SPL. Ten SPL values are obtained for each respondent in a span of half a minute. The average SPL was then computed from the ten measured values. The respondents were also asked of the frequency and the average duration of their music listening in a day.

5. Results and discussions

5.1. Characterization of PEC models
The normalized power spectrum of computed from the inside of the engineering plastic PEC is shown in Figure 3 for the different lengths. The vertical axis of the graph shows the SPL and the horizontal axis indicates the frequency of the sound. It can be seen that the graph peaks between 3 kHz and 4 kHz. This is consistent with the frequency response characteristic of the actual ear canal [6-8]. Similar trend were also exhibited by the steel PEC hence the PEC frequency response characteristic is material independent. The frequency response of the PEC is only affected by its length as can be seen in the slight difference of the frequency response for the different length. Ear canal also amplifies sound emitted by the earphones as can be noted in the positive values of the normalized power spectrum. This is due to the confinement of the sound resulting to the sound energies directed towards the microphone or to the ear drum in real situation. With the similarity of the PEC acoustical characteristic to that of actual ear canal, it can be safely assumed that the PEC can represent closely the sound propagation process in the actual ear canal. Hence, PEC can be a useful substitute to an actual ear canal in the SPL measurements inside the ear canal.

Figure 3. The graph showing the engineering plastic PEC models frequency response. In decreasing order, blue line shows the frequency response of the longest sample, followed by green and then the red.

5.2. Measurement of SPL with earphones
A total of 266 respondents participated in the ear canal SPL measurement. The histogram of the average SPL is shown in Figure 4. The average SPL ranges from about 65 dB up to 105 dB. The most
frequent SPL of the sample set is estimated to be around 80-85 dB. This range of SPL is comparable to the noise generated in a busy street. It can also be seen that quite a number of respondents (about 35% of the total sample size) are using excessive volumes (85 dB and above) in their music listening. While it cannot be conclusively stated that these respondents are in the risk of having hearing loss or are already hearing impaired it is clear that a percentage of the populace has the tendency to use excessive loud music and therefore need to be effectively warned.

Incorporating the listening duration per day to the measured SPL, a scatter plot of the SPL versus duration for all 266 respondents is shown in Figure 5. The dash-line in the graph represents the noise level and recommended daily exposure duration by the WHO. The plot shows that about 21% of the respondents, points in the right of the dash-line, exceed the exposure duration set by WHO. These respondents have a risked of acquiring noise induced hearing loss (NIHL).

![Figure 4. Histogram of the sound pressure level.](image)

![Figure 5. The red broken line shows the standard set by the WHO for the amount of time exposure for a specific loudness level. The asterisks are the data for the 266 respondents of the average time of exposure vs. the sound pressure level in music listening.](image)
6. Conclusion
We have modeled an ear canal as hollow cylinders with dimensions representative to the actual dimension of an ear canal. The physical ear canal model has a peak frequency response in the range of about 3 kHz up to 4 kHz. The acoustical properties of the physical ear canal model are comparable to the acoustical properties of a real ear canal basing from literature. This allows the model to be a substitute for the real ear canal for sound pressure level measurement.

Approximation of the sound pressure level inside the ear canal during music listening of the sample set of the populace was carried. To minimize the complexity of the experiment, a physical ear canal model was utilized instead of the actual ear canal of the respondents. We have found out that the most of frequent sound pressure level of the respondents is within 80 dB to 85 dB. Thirty five percent of the respondents listen to music with an average of more than 85 dB SPL. In comparison to the WHO standard for noise exposure level, about 21% of the respondents exceed the WHO criteria. In conclusion, we have successfully approximated the sound pressure level during music listening. The result of this study could be used in formulating effective warnings to minimize noise induced hearing loss of the listener.

As a recommendation, it would be important to include more respondents to have a much better statistics. It is also interesting to correlate the sound pressure level with that of background noise level to identify potential behavior of the listener.

References
[1] U.S. Department of Health and Human Services 1998 Criteria for a Recommended Standard: Occupational Noise Exposure, Revised Criteria 1998 (Ohio: Public Health Service Centers for Disease Control and Prevention National Institute for Occupational Safety and Health)
[2] Levey S, Fligor B, Ginocehi C and Kagimbi L 2012 Contemporary Issues in Communication and Disorders 39 76–83
[3] Hiipakka M T2008 Measurement Apparatus and Modelling Techniques of Ear Canal AcousticsMaster Thesis, Helsinki University of Technology, Helsinki, Finland
[4] Moore K L and Dalley A F 1980 Clinically Oriented Anatomy (Lippincott Williams & Wilkins) pp 962–76
[5] Shier D, Butler J and Lewis RHole’s Human Anatomy & Physiology (New York: McGraw-Hill) pp 454–62
[6] Pielemeier W H 1946 Journal of the Acoustical Society of America 18 248
[7] Mehrgardt S and Mellert V 1977 Journal of the Acoustical Society of America 61 1567
[8] Shaw E A G 1974 Journal of the Acoustical Society of America 56 1848–61