

THE STATISTICAL DISTRIBUTION OF EXPECTED NOISE LEVEL OUTPUT FROM COMMONLY AVAILABLE PERSONAL STEREO PLAYERS

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This work presents a summary of the equivalent at-ear sound levels that can be expected to be experienced by users of personal stereo players. Estimates of inter-device and inter-earphone variability are also provided along with variations in performance and maximum output levels. This variation in acoustic output levels may mean that attempts by users to control noise exposure by monitoring the electrical output may not be as simple as first envisaged. A simple method is provided for the estimation of PSP output level with respect to the volume setting.

INTRODUCTION

Since the introduction of personal stereo players (PSP) there has been increasing discussion and speculation concerning the possible levels of overall noise exposure from excessive listening by users (Rice, Breslin & Roper: 1987; Waugh & Murray: 1989; Passchier-Vermeer: 1999; Fligor & Clarke Cox: 2004; SCENIHR: 2008). Acoustic output levels from devices and their associated earphones have been measured in the laboratory (Waugh & Murray: 1989; Turunen-Rise, Flottorp & Tvette: 1991; Passchier-Vermeer: 1999; Fligor & Clarke Cox: 2004; Portnuff & Fligor: 2006; Keith, Michaud & Chiu: 2008), in situ in common use settings (Williams: 2005; Williams: 2009) and in a mixture of the laboratory and in situ (Rice, Breslin & Roper: 1987). The conclusions from this work agree that given the available levels of acoustic output there is a distinct possibility of noise injury and subsequent hearing loss with excessive use (Lonsbury-Martin & Martin: 2007; Morata: 2007).

Laboratory measurements produced by six compact disc players and a range of nine commercially available headphones were carried out by Fligor and Clarke Cox (2004) using specifically recorded 'white' noise and a selection of CDs from eight music genres. The A-weighted output levels at maximum volume setting with the white noise ranged from around 94 to 115 dB. Keith et al (2008) specifically measured the A-weighted output levels at maximum volume setting from various combinations of portable digital audio players and headphones with results ranging from 101 to 107 dB for headphones when worn as would be normally expected with a 'loose' fit. If the headphones were fitted with a 'tight' fit, such as having ear phones under a head ('sweat') band or a greater clamping force on earmuffs, it was observed that the output level could increase on average by 16 dB to a maximum in one case of 120.4 dB.

A combination of laboratory and in situ measurements found maximum A-weighted levels extended over 100 dB for 5% of users with one reaching a maximum of 107 dB (Rice,

Breslin & Roper: 1987). From the presentation of the data it is unclear how these values were distributed between laboratory and in situ measurements. In another study of 139 participants in situ, the maximum A-weighted output level was recorded as 110 dB (Williams: 2009).

Currently social research examining PSP use and possible problems of over exposure to noise and subsequent noise injury frequently makes use of interviews and questionnaires. Rather than attempt the time-consuming task of an on-site measurement of PSP acoustic output level users are asked to rate the volume setting they typically set on their device. This is usually expressed either as a single figure rating from one to ten or as a percentage of maximum output. In contrast, this project looked at what acoustic output level could be expected in relation to the volume setting. Social researchers can then estimate the approximate noise exposure of PSP users within a given confidence interval.

METHOD

Ten different PSP devices and 17 different earphones were tested. Samples were gathered after a request for volunteers to lend their PSPs for measurements. All testing was carried out at the National Acoustic Laboratories, Chatswood. As it was not logistically possible to have all of the PSPs and headphones assembled simultaneously during the testing period the most desirable situation of testing all devices and earphone combinations was not possible. Hence the following combination of devices and headphones were measured: a) 10 devices with as many compatible/available headphones as possible making a total of 45 combinations; b) one device with each of 12 earphones and three devices with each of eight earphones to examine earphone variation; and c) one earphone with each of six devices and three earphones with each of four devices to examine device variation. A comprehensive list of device – earphone combinations tested is supplied in the attached Appendix.

The acoustic output level measurements were carried out using a previously utilised system (Williams: 2009) consisting of a lightweight manikin head fitted with a Zwislocki artificial ear simulator including pinna. The artificial ear simulator was in turn fitted with a B&K 4134 pressure response microphone, supported by a B&K 2639 preamplifier and B&K 2804 microphone power supply leading to a B&K 2231 Integrating Sound Level Meter. The system was calibrated using a B&K 4230 calibrator. The output levels under earphones are expressed as the equivalent diffuse field, A-weighted equivalent continuous sound levels (LAeq) as per AS/NZS 1269.1: 2005.

The measurements were performed using one of the earphones from the PSP by placing it around, over or in the measurement ear depending on whether it was a circum-aural, supra-aural or an insert earphone, while the PSP was playing. The noise level under the earphone was measured in accordance with the recognised procedure as per AS/NZS 1269.1 (2005), Appendix C (Informative), “Recommended procedures for measurement of sound pressure levels from headphones or insert earphones”. The measurement parameter was the L_{Aeq} taken over a two minute (120 sec) period. This sample time was selected so as to adequately ‘average’ the representative noise level of the PSP and in line with previous practice (Rice, Breslin & Roper: 1987; Williams: 2005; Williams: 2009).

The song or music playing was ‘pseudo-randomly’ selected to represent that typically used by owner of the device. For example, this may have been a frequently listened to or favourite selection. In this way it was intended to sample the range of outputs experienced by a large number of users. The acoustic output levels were measured at the 35%, 50%, 65%, 80%, 90% and 100% volume setting as judged by the ‘volume indicator’ on all of the devices used. These levels were selected as representative of the range of typical listening conditions.

RESULTS AND DISCUSSION

a) Overall

Figure 1 presents a specific example of the output from a well-known, good quality device with matching ‘ear-bud’ earphones together with a line of best fit between the volume settings and measured outputs. This particular device was tested with volume settings from 10% to 100%. As would be expected of a well-engineered player there is good linearity with a clear, linear relationship between the measured output level and the indicated volume setting and 100% output corresponds to an LAeq of about 100 dB. Unfortunately this is not the case with all device – earphone combinations.

The acoustic output levels measured from the 45 device – earphone combinations are presented graphically in Figure 2 along with the mean output level (solid line). As can be seen there is a wide range of output levels for a selected volume setting. These vary with an overall average of 34 dB, from a minimum of 23 dB at 35% volume setting to 45 dB at the 100% volume setting. The range increases roughly proportional to the selected volume. Overall there is an increase in output level with increase in volume setting however this is not the case with all device – earphone combinations. One combination

resulted in an almost flat response with higher outputs for lower settings (see Figure 3). There is a general tendency for non-linearities to occur at low volume settings.

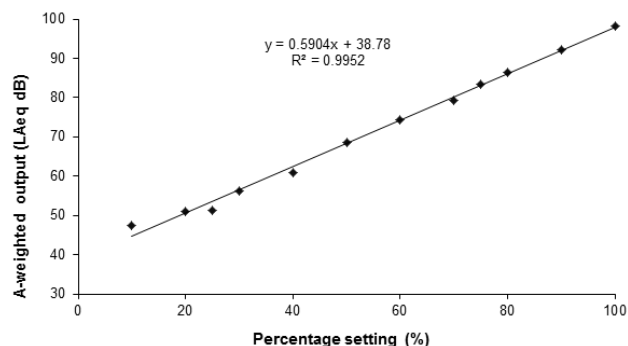


Figure 1: The relationship between measured acoustic output (L_{Aeq}) and volume setting (L) of a combination of a good quality PSP and matched earphones.

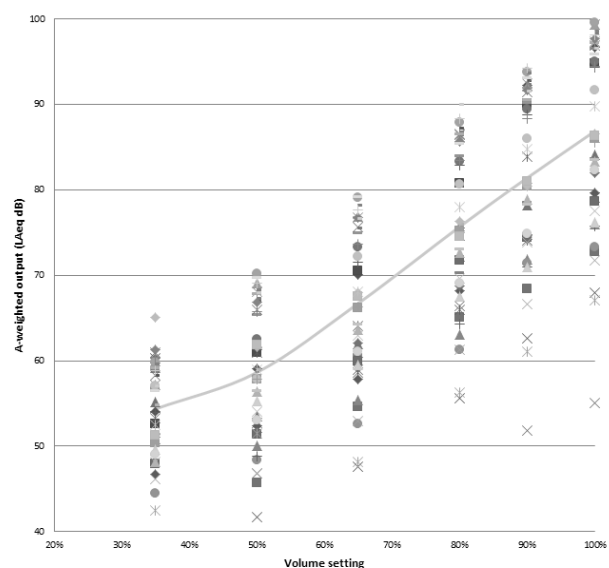


Figure 2: Measured acoustic output (L_{Aeq}) and volume setting (L) for all 45 PSP – earphone combinations tested. The solid line represents the expected (mean) value.

The general relationship for all devices is provided by the trend line, viz: expected output = $0.53 L\% + 34$ ($R^2 = 0.99$). The average standard deviation (SD) for all volume settings is 8.8dB monotonically increasing from 5.3 dB at 35% to 10.9 dB at 100% output. The upper 95% confidence interval for the output level at 100% volume setting is 108 dB.

The variation in performance has two main sources discounting any variation that may arise from music or song selection. The two obvious sources are the devices and the headphones.

b) Earphone variation

One device was tested with six different devices and three sets of earphones were tested with each of four devices. The

device tested with each of six different earphones gave an average SD of 7.3 dB. Four of these earphones were the same as used with the subsequent three devices. The devices tested with each of the same four earphones produced average SDs of 8.0 dB, 9.2 dB and 9.8 dB. The average SD across all tests of 8.6 dB could be considered the between-earphone variation.

c) Device variation

One PSP was tested with each of 12 earphones while three devices were tested with each of eight different earphones. These eight earphones were included in the testing with the 12 earphones tested with the first device. The SD for the test with 12 earphones was 6.0 dB while the other three tests produced SDs of 4.9 dB, 6.9 dB and 8.5 dB with an average value of 6.6 dB. This is representative of the between-device variation.

General discussion

The implication of the SDs for the earphones and devices is that more variation should be expected between earphones as compared to the variation between devices. Figure 3 illustrates the variation possible showing two different device earphone combinations with their volume settings. One well behaved combination (solid line) behaves reasonably as would be expected, while the second (broken line) shows very irregular and poor performance.

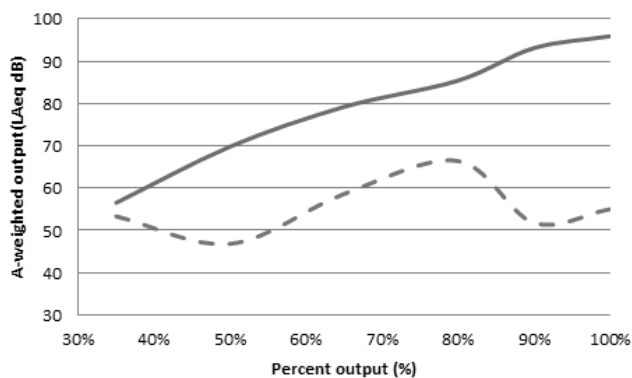


Figure 3: The acoustic output – volume setting for two device – earphone combinations showing good performance (solid line) and poor performance (broken line).

From an engineering perspective this variation of acoustic output levels is to be expected and can arise from many sources including impedance mismatch between device and earphone; variation in electrical signal sensitivity between earphones; quality control during production; ageing and wear of players and earphones; power supply (battery) variations; and device amplifier and power supply design and performance criteria. All devices are not designed or produced to the same specifications or criteria.

While Figure 3 clearly shows the differences in performance possible, it is observed that the more well-known and popular device – earphone combinations tend to provide higher output levels compared to those not so well known or as popular. Devices combined with their supplied earphones also

tend to have more regular performance compared to mixed combinations. Measured maximum outputs greater than 90 dB are more common (20) compared to those measuring less than 80 dB (11) at maximum volume setting.

If comparisons are made to regulated workplace noise exposure standards where an eight hour, equivalent continuous A-weighted sound pressure level (LAeq,8h) greater than 85 dB is deemed to be hazardous, then users with outputs of 97 dB, using the equal energy 3 dB exchange rate, will reach their allowable exposure with only 30 minutes of use. In the current survey 13 of the 45 device – earphone combinations provided outputs at or greater than 97 dB. It is a reasonable conclusion to draw that regular use of PSPs at these levels does have the potential to cause a predictable and significant hearing loss over the long term (ISO 1999: 1990).

One notable consequence arising from the wide variation in acoustic output relates to suggestions frequently made to legislatively limit PSP output to ‘safe’ levels (Hellström, Axelsson, Costa,; 1998; Vogel, Brug, Hosli, van der Ploeg, & Raat: 2008; Vogle, Verschuure, Ploeg, Brug & Raat: 2009; Snowden & Zapala: 2010). The only reliable method of regulating acoustic output levels would be to actually monitor the acoustic signal in the ear. If exposure control is attempted by simply monitoring the electrical signal to the earphones then this will be unreliable as demonstrated above. This unreliability could be due to such causes as different electrical sensitivities between earphone types and impedance mismatching.

Exposure prediction

If general users, social researchers or anyone with an interest needs to estimate the potential noise exposure of individuals who regularly use PSPs the graph presented in Figure 4 would be of some use. For example, if a user states that they regularly have the volume set at around 80% an exposure estimate of 76 dB can be made with a 95% confidence interval of about 58 dB to 94 dB. This can provide typical, best- and worse-case estimates for possible noise exposures from PSP use.

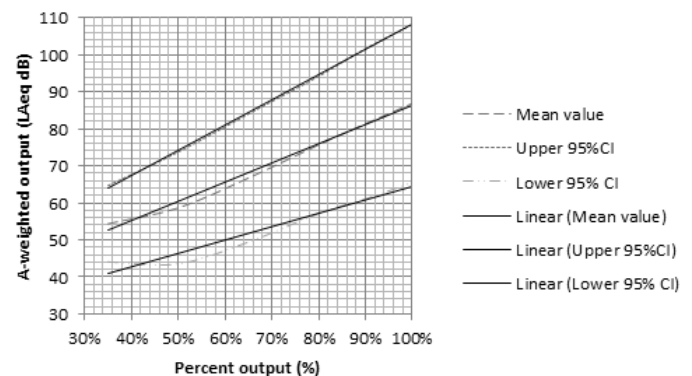


Figure 4: The estimation of expected and range of acoustic output levels from commonly available personal stereo player and earphone combinations with linear approximations for the mean and upper and lower 95% confidence interval value.

CONCLUSION

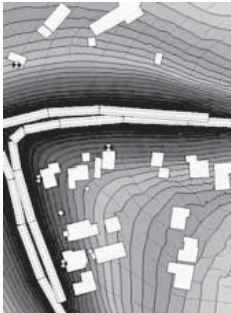


It was found that there is significant variation in acoustic signal output level from PSP use dependent on the device – earphone combination. At upper volume settings these variations can be in the order of 40 dB. While the level of the acoustic output has the potential to cause noise injury and hearing loss with extended exposure, the obvious solution of controlling exposures by electrical monitoring of the output signal may not be as simple to implement as first envisaged.

ACKNOWLEDGEMENTS

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