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Validity of a temporary threshold shift (TTS) detector for use with portable listening devices

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ABSTRACT

Recent studies on the use of portable audio listening devices indicate that while sustained listening at the maximum output volume of the unit is potentially hazardous with most devices, personal habits and listening preferences during actual use are such that only a 5-10% fraction of users may be at high risk of developing permanent hearing damage. Given the explosive increase in sales for these devices in recent years, this nevertheless represents a very large number of individuals worldwide. In this project, self-administered auditory temporary threshold shift (TTS) measurements are investigated as a possible tool to raise user awareness on the potential risks of portable listening devices when used at excessive levels. Users are presented with a sequence of 10 tones varying in levels near threshold using their device, and are asked to count the number of tones heard before and after the listening session. Counting less tones after the exposure indicates the presence of a TTS. Test-retest reliability measurements indicated that a TTS of 5 dB or more could be detected with this method. A validation study is currently being carried out in a laboratory setting with a group of users with normal hearing. Subjects must listen to music with their own devices for a one-hour session in a simulated bus noise environment. Thresholds are measured prior to and after exposure using the proposed method of counting and a fixed-frequency adaptive tracking method as control. Listening levels are also monitored using a KEMAR manikin. Preliminary results indicate that a fraction of subjects develop a TTS of 5 dB or more, which is typically shown with both threshold methods. Interestingly, these subjects all listened to music at levels exceeding 90 dBA during the session. It is hoped that such a tool could help users self-detect potentially hazardous situations and foster safer listening practices.

INTRODUCTION

The increased popularity of portable audio devices is raising concerns regarding exposure to potentially hazardous sound levels (SCENIHR, 2008). With advanced miniaturization and digital signal processing, greater sound quality and longer battery life than previous systems (Vogel et al., 2008), new portable audio devices can be used for hours without interruption (Kenna, 2008). Given the phenomenal increase in sales for these devices in recent years (SCENIHR, 2008), individuals can nowadays be seen listening to music everywhere: at home, at work, while exercising, walking and in transit (Ahmed et al., 2007; Kenna, 2008).

Adolescents and young adults are particularly susceptible to music-induced hearing damage. Indeed, the majority of university undergraduates own at least one device (Ahmed et al., 2007) and adolescents listening to portable audio devices frequently report tinnitus (Vogel et al., 2008). Likewise, a survey by Zogby (2006) revealed that high school students typically listen to portable audio devices at higher levels and over longer periods, and report a greater incidence of tinnitus and difficulty communicating. Length of use is also variable. Approximately half of the sample in the Torre (2008) study reported using their device for 1 to 3 hours per day.

Of particular concern, several studies indicated sound levels often in excess of 100 dBA and sometimes reaching 115-120 dBA when personal listening devices are set at the maximum volume setting (Fligor and Cox, 2004; Ahmed et al., 2007; Hodgetts et al., 2007). Actual exposure depends on several factors including the surrounding background noise environment, earphone attenuation and style, and the type of activity (Airo et al., 1996; Williams, 2005; Russo et al., 2007; Fligor, 2008; Hodgetts et al., 2009). Considering personal habits and preferences in volume settings and duration of listening during daily use, it is estimated that about 5-10% of users are at high risk of permanent hearing damage, and typically these are individuals listening at the high volume settings over an hour daily (SCENIHR, 2008).

From these findings, it is clear that prevention strategies against music-induced hearing loss need to be adopted and targeted at those most at risk. Measures at the level of the devices can be implemented (output limiters, warnings, regulations), but raising awareness in end users remains critical. Indeed, individuals most at risk are likely those who are not worried about their hearing health and those less knowledgeable about the long-term hazardous effects of high sound levels (Ahmed et al., 2007).

One immediate effect of high sound exposure is the temporary shift in hearing thresholds that builds up over time and persists several minutes or hours following exposure. Indeed, a few studies indicated the presence of temporary threshold shifs (TTS) in some users following exposure to music with personal music players (Lee et al., 1985; Turunen-Rise et al., 1991; Loth et al., 1992). The amount of TTS varies widely across individuals and listening conditions, but can sometimes reach 15 dB or more. Further, large temporary shifts appear associated with high sound exposures. While these elevated thresholds typically recover with time, repeated and/or excessive exposures may result in permanent shifts.

In the hope of fostering safer listening behaviors and preventing permanent hearing damage, a group of researchers (Laroche et al., 2009) has proposed a novel approach to raising awareness among users, consisting of a TTS measurement tool to be integrated into portable audio devices. The user-administered measurement method consists of 10 tones varying in sound pressure level (SPL) at a 2.5 or 5 dB step size. The user is required to count the number of tones heard prior to (when the device is powered on) and following (when the device is turned off) exposure to music. The degree of TTS is estimated as the difference between the number of tones counted before and after, times the level step size. The test must be performed in relatively quiet environments.

Laroche et al. (2009) describe the steps involved in determining the optimal parameters (test frequency, level step size, threshold measurement method), as well as testing the feasibility and repeatability of the approach. The following electroacoustic and subjective tests were performed: (1) effect of battery life on sound levels, (2) sound attenuation provided and maximum output produced by various types of earphones, (3) linearity of portable audio devices, (4) repeatability of the counting threshold task and effect of earphone placement, and (5) effect of background noise on TTS measurements. Six portable listening devices and eight sets of earphones were investigated in total over the different tests. Steps (4) and (5) were carried out using 20 individuals with normal hearing.

Two modes of stimulus delivery illustrated in Figure 1 were examined: an ascending mode (upper panel) and a random mode (lower panel). Overall, results can be summarized as follows:

- The effects of battery life on output levels (Step 1) and the linearity of portable audio systems (Step 3) would not contaminate the proposed TTS measure.
- Typical within-subject standard deviation of threshold measurements was 2.5-3 dB, including placement effects (Step 4).
- Earphone attenuation (Step 2) is a primary determinant of the maximum background noise in which threshold measurements can be performed (Step 5). In general, background noise should not exceed 35-40 dBA for threshold measurements with low or no attenuation earphones. Threshold measurements in higher background noise levels require attenuating earphones.
- Better test-retest reliability was obtained from 4-8 kHz than at 10 kHz. Given the generally greater incidence of TTS at 4-6 kHz than at 8-10 kHz (Schumuziger et al., 2007) and greater susceptibility to noise effects around 4 kHz, 4 and 6 kHz were deemed more adequate for TTS measurements.
- A slight advantage of the random presentation over the ascending presentation was noted in terms of test-retest reliability.
- Similar resultats were found for the level step sizes used (2.5 and 5 dB steps).

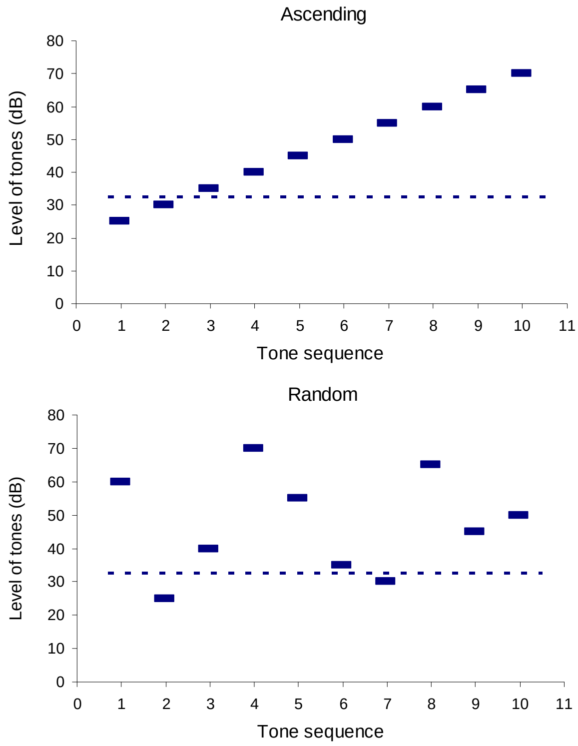

Figure 1. The two proposed modes of stimulus presentation [upper panel = ascending presentation; lower panel = random presentation]. The dotted line represents the individual's threshold. In this example, eight tones are above threshold.

The objective of this follow-up study was to validate the proposed tool by measuring TTS in individuals exposed to loud music with their own devices, and comparing results to those obtained using a previously validated, audiometrically-based, TTS measure – the method of adjustment.

METHODS

Participants

Twenty young adults (9 males and 11 females) with a mean age of 23.8 years old took part in the study. Participants had normal otoscopy and tympanometry results, in addition to hearing thresholds ≤ 25 dB HL from 250 to 8000 Hz.

Methods

Following otoscopy, tympanometry and the measurement of hearing thresholds at audiometric frequencies from 250 to 8000 Hz, pre-exposure measurement of hearing thresholds at 4 and 6 kHz was performed in a soundproof room, using two different methods. Testing was performed in one ear only and the test ear was counterbalanced across subjects.

During the method of adjustment, lasting 30 seconds per threshold measurement, participants are required to press a button upon hearing the signal and release the button when the signal is no longer heard. The level of the signal is automatically adjusted based on the participant's responses. The new proposed approach, the method of counting, lasts 15 seconds per threshold measurement. The test signal (4 or 6 kHz tone) is presented 10 times, using 2.5 dB steps and random presentation, and participants are required to count the number of signals heard. To limit ceiling effects during TTS measurements, the SPL is initially adjusted to ensure that participants perceive 6-8 signals during the pre-exposure trial. Both methods used software developed in-house to present the test stimuli, and all signals were calibrated.

Participants where then asked to listen to music played through their portable audio device in the presence of a 75-dBA bus noise diffuse sound field, after adjusting the volume of the device at a preferred setting in this background noise. A one-hour continuous exposure to music followed, without modifications to the volume setting. It should be noted that most participants used intra-concha earbud earphones, except for two participants (1 and 16) who wore in-the-ear type earphones.

Approximately two minutes following the music exposure, 4 and 6-kHz thresholds were measured using both methods. The order of the test frequency and that of the measurement method were again counterbalanced across subjects. The difference between pre- and post-exposure measurements yielded the temporary threshold shift measured approximately 2 minutes following the exposure (TTS-2).

Finally, individual listening levels were documented using KEMAR and a sound level meter (B&K 2250). The last song played with the device was presented through the earphones fitted on the KEMAR. Third-octave correction factors were used to transform measured manikin levels into equivalent diffuse field values (ISO 11904-2, 2004).

RESULTS

Preferred listening levels in 75-dBA noise

Diffuse field equivalent levels at the preferred volume setting are displayed for each participant in Figure 2. Across participants, preferred listening levels ranged from 62.5 to 105.3 dBA, with a mean of 84.6 dBA, thereby representing a signal-to-noise ratio of 9.6 dB (s.d. = 10 dB). Listening levels exceeding 90 dBA were measured in 6 subjects out of 20 (30% of the sample), one (5% of the sample) of which listened to music exceeding 100-dBA listening levels.

According to WHO guidelines (WHO, 1999), exposure should be limited to 75 dBA-8h to limit potential damage. Applying the 3-dB exchange rule, 90-dBA listening levels for a period of 15 minutes yields the same noise exposure. As the exposure lasted for one hour in this study, it was anticipated that TTS would occur in some participants.

Results on preferred listening levels are consistent with those of previous studies. A mean listening level of 85 dBA was reported by Rice et al. (1987). In the same study, 25% of the sample listened at levels greater than 90 dBA, while 100-dBA levels were exceeded in 5% of listeners in the Fligor & Cox (2004) study. Similarly, average SNRs of 14 dBA (Airo et al., 1996) and 13 dBA (Williams, 2005) were obtained in 72-dBA and 73-dBA background noise, respectively.

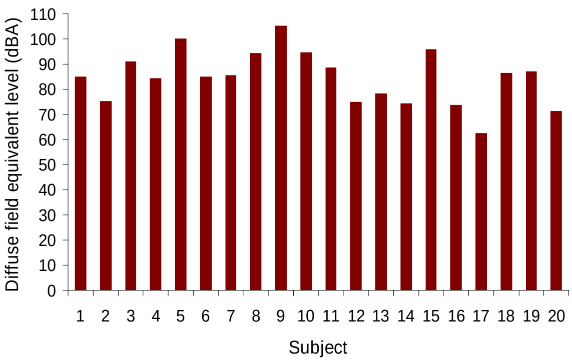

Figure 2. Preferred listening levels in 75-dBA bus noise.

Temporary threshold shift at 4 and 6 kHz

Temporary threshold shift was calculated as follows for the two measurement methods. For the method of adjustment, TTS was obtained by substracting pre-exposure thresholds from post-exposure thresholds. In the method of counting, results are expressed as the number of tones heard, hence the pre/post- exposure difference needed to be multiplied by the step size (2.5 dB) to yield a TTS in dB.

TTS at 4 and 6 kHz are displayed in Figure 3. Positive values are indicative of TTS. Of those exceeding 90-dBA listening levels (participants 3, 5, 8, 9, 10 and 15), half presented a measurable TTS greater than 5 dB at either frequency, using both measurement approaches. Results vary widely across participants, a finding consistent with the variability in individual susceptibility to noise effects reported in the literature.

The most significant shifts in hearing thresholds were noted in the participant with listening levels exceeding 100 dBA (participant 9). Using both methods, TTS ranged between 5-7.6 dB and 7.5-10.9 dB at 4 kHz and 6 kHz, respectively. Following the exposure, this individual also reported bilateral tinnitus, reduced sensitivity to sound and difficulty understanding speech.

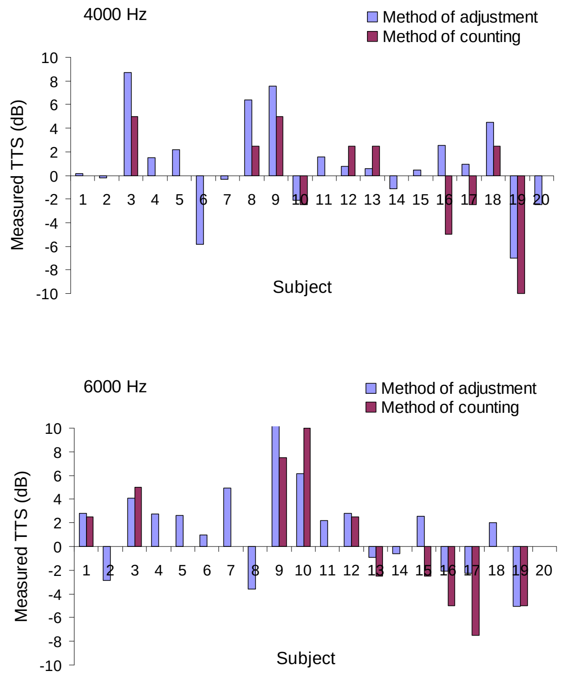

Figure 3. Individual measured TTS-2 using both methods [upper panel = 4 kHz; lower panel = 6 kHz].

Comparison of two measurement methods

To validate the new proposed approach, results were compared to those obtained using a previously validated method serving as the gold standard (the method of adjustment). The amount of TTS measured with the counting method is therefore displayed as a function of TTS measured with the method of adjustment in Figure 4.

At 4 kHz, the regression line has a slope of 0.6 dB, indicating that each dB of TTS measured with the method of adjustment corresponds to approximately 0.6 dB of TTS measured using the method of counting. The r-squared valued is 0.48, with large dispersion of data about the regression line.

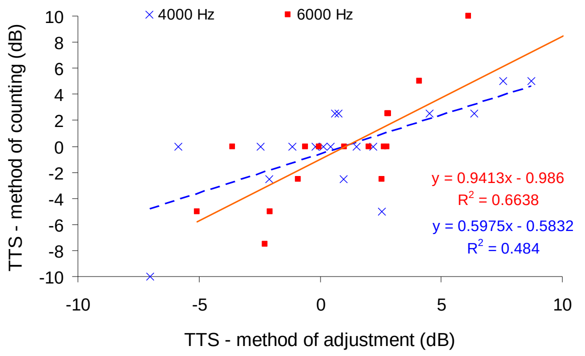

Figure 4. TTS measured with the method of counting as a function of TTS obtained with the method of adjustment.

At 6 kHz, the slope approaches 1 dB (0.9 dB) and the r-squared value is higher (0.66), indicating a better correspondance between results obtained with both approaches. Better correlation at this frequency militates in favour of using a 6-kHz signal in the proposed tool.

Effect of listening levels on measured TTS

To observe the effect of listening levels on threshold shifts, measured TTS is plotted as a function of preferred listening level in Figure 5. Although similar r-squared values are obtained using both measurement methods, which appear to behave similarly when relating TTS to listening levels, correlations are slightly better at 6 kHz than at 4 kHz. Overall, however, both factors are not strongly correlated, at least in the sample studied, a finding that could be attributable to the generally low incidence of significant TTS in this study.

The slope of the function is equally shallow. At best, the 0.2-dB slope at 6 kHz would suggest that each dB increase in listening levels would generate a 0.2 dB shift in hearing thresholds.

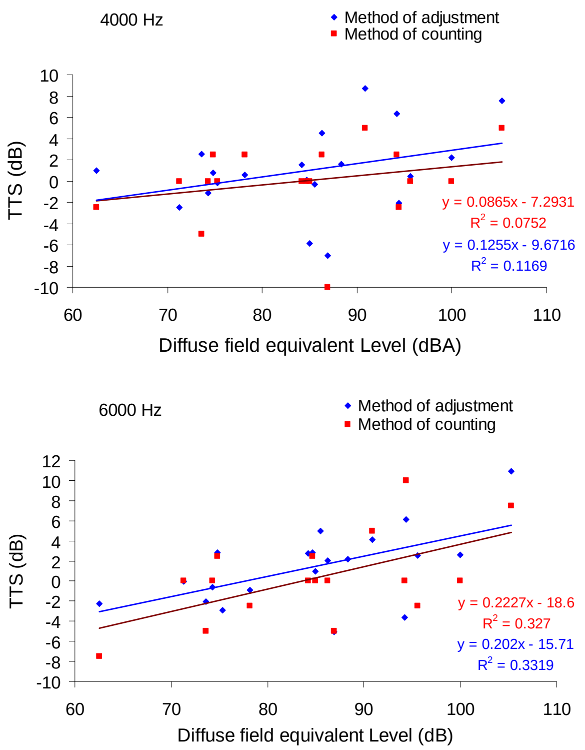

Figure 5. Measured TTS as a function of preferred listening levels [upper panel = 4 kHz; lower panel = 6 kHz]

CONCLUSIONS

A simple TTS detector based on the difference in the number of tones counted before and after exposure to music presented through portable listening devices was investigated. According to a previous study on the development of the proposed measurement tool (Laroche et al., 2009), a TTS of 5 dB could be reliably detected with a confidence interval of 95%, using a random presentation approach and 2.5-dB steps.

In the current sample, a TTS of this magnitude was obtained in 3 participants who also showed a TTS of at least 4 dB with the method of adjustment, which served as the validated gold standard approach during comparisons. Interestingly, the 3 participants who showed significant TTS listened to music at levels exceeding 90 dBA, with the greatest shift found in the individual whose preferred listening level in background noise exceeded 100 dBA.

Overall, the proposed method of counting appears promising to detect TTS equal to or greater than 5 dB in normal hearing individuals, following one hour or longer exposure to music in moderate background noise. As greater correlation was found between both methods using a 6-kHz tone, this is the recommended test signal. It should however be noted that for valid and reliable results, measurements should be carried out in relatively low background noise levels (35-40 dBA).

Other than the influence of background noise levels, another limiting factor is related to the potential difficulty of measuring TTS in an already damaged ear. In such cases, TTS could occur at higher exposure levels than in normal ears (Axelsson and Lindgren, 1978), and the absence of TTS would not necessarily suggest that the individual is not at risk of further damage. In the current study, all listeners had normal hearing, which would not be the case for all users of portable listening devices.

Further validation with more participants, various background noise levels and prolonged exposure is anticipated, prior to implementation. When integrated into portable devices, it is hoped that it will help raise awareness, foster safer listening practices, and limit music-induced damage from excessive or unsafe use.

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