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A study of hearing damage caused by personal MP3 players

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ABSTRACT

This paper aims to assess the actual in-hear sound pressure level during use of mp3 players. The method is based on standard EN 50332 (100dB as maximum SPL), IEC 60959 (HATS) and IEC 60711 (ear simulators), as explained in the January 2007 issue of the Bruel and Kjaer Magazine (page 13) [1].

In this study a number of MP3 players were tested, employing a dummy head and a software for spectrum analysis. The measurements were aimed to assess the hearing damage risk for youngsters who employ an MP3 player for several hours/day.

The students of an Italian high school (15-18 years old) were asked to supply their personal devices for testing, leaving untouched the gain from the last usage.

The results show that the risk of hearing damage is real for many of the devices tested, which revealed to be capable of reproducing average sound pressure levels well above the risk threshold.

1. INTRODUCTION

The goal of this paper is to provide a very preliminary assessment of the noise-induced risk caused by the usage of personal digital audio players (DAP) among teenagers.

The assessment has been performed by experimental analysis of the sound pressure level caused at the eardrums when wearing headphones being fed by a DAP, playing the typical music pieces which are preferred by today's teenagers.

This research is aimed at goals slightly different by those of other works which appeared recently, and which make use of apparently similar measurement techniques, as for example those of Hodgetts [2], Ahmed [3] and Williams [4], which are all referred to adult population, and do not take into account the peculiar type of sound samples actually found on the DAPs used by teenagers in Italy. In fact, it was first necessary to analyze the content of these devices, which revealed to deviate significantly from the "standard" IEC music programme employed as stimulus in other surveys. After an alternative artificial test signal has been created, more corresponding to the spectral and dynamic characteristics of these music pieces, the measurement of the sound pressure level of several devices has been performed employing a method derived by the currently available EN standard 50332 [5], and taking into account the suggestions provided by Temme [6].

The analysis of the result has shown that the risk connected with systematic usage of these portable DAPs is real, and that more strict regulations should be enforced for impeding excessive exposure of teenagers.

2. METHOD

The method employed is derived from the standard EN 50332, and is thence quite similar to it. In fact both methods are based on playing a test signal through the mp3 player and to analyze the sound with a head and torso simulator. However the standard method aims to measure the maximum sound pressure level of which the device is capable, while this paper's aim is to assess the SPL to which an average teenager is exposed, so the method was specifically tailored for this purpose.

2.1. IEC Test Signal

Programme simulation noise was used according to EN 50332 and IEC 60268-1. First we generated 1 minute of pink noise using the Generate Noise module of Adobe Audition, to which a frequency filtering (using the Graphic Equalizer module) was applied in order to obtain a signal with the correct spectrum. The sound thus obtained was analyzed with the Statistical Analysis function of Audition, from which resulted that the signal (which had been normalized with a maximum peak value of 0 dBFS) had average RMS value of -16 dBFS instead of -10 dBFS as prescribed by the IEC/ITU standard. In order to increase the energy content without altering the spectrum, the Hard Limiting module of Audition was employed, setting a 6 dB gain. The necessary dynamic compression was thus produced, bringing the RMS value to -10 dBFS. However this action also caused a minor spectral distortion. In order to correct this, the spectrum was analyzed in 1/3 of octaves using Spectra RTA. The Graphical Equalizer module was used once again to correct the spectrum. The resulting sound was measured compliant both with the frequency spectrum and the -10 dBFS RMS value requested by the IEC standard.

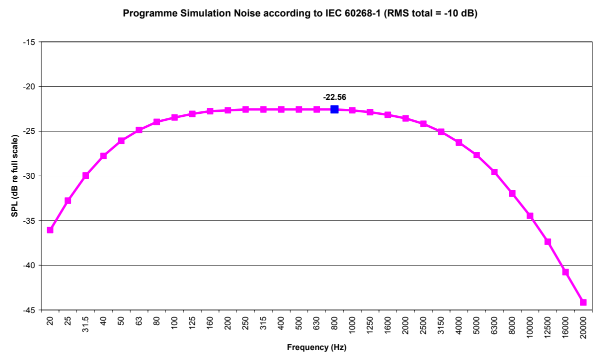

Figure 1 Spectrum of the IEC test signal

2.2. "MUSIC" Test Signal

The IEC test signal is good for assessing the maximum SPL for a device, but it is not a good simulation of music, as his spectral content is not really representative of music signals. Since this paper doesn't aim to assess the maximum SPL possible, but the average SPL during music playback, another signal was used too. In order to produce a sound that had the spectrum of an average song we collected more than 30GB (more than 13h) of music of various genres and periods among the users of the measured devices. An average 1/3 of octave spectrum was measured from this music using Spectra RTA (receiving digitally the audio input via a program called Virtual Audio Cable).

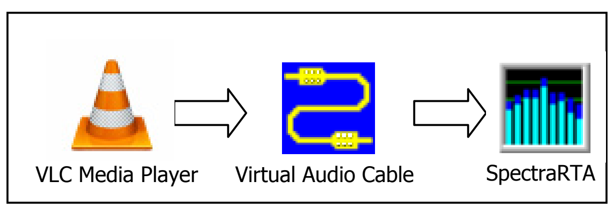

Figure 2 Data flow for analyzing the spectrum of a list of music pieces

Apart from the average spectrum, it is also interesting to observe the "time history" of the sound pressure level, measured with a time constant "slow" (1 s): this provides some information about the variability of the level of modern music in the time domain.

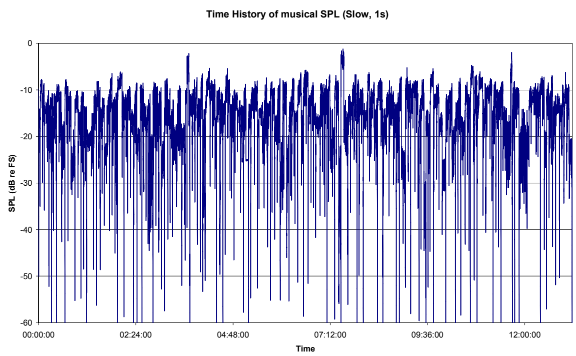

Figure 3 Time History of 13h of music pieces

The generation of the second ("MUSIC") test signal was done using the same method employed for the IEC music programme test signal.

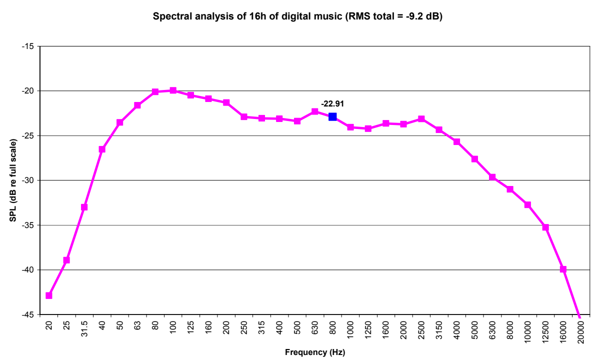

Figure 4 Spectrum of real-world music samples

It can be seen from the comparison between figures 1 and 4 how the "real" music spectrum has more bass content than the IEC test signal, and the average RMS value is -9.2 dBFS instead of -10 dB, as a consequence of the fact that modern pop and rock music is heavily amplitude-compressed.

2.3. File formats employed

In order to perform the measurements the test signals were put on the digital audio players using the best codec available for each device (uncompressed wav when available).

The formats employed are the following:

- Uncompressed WAV (44100 Hz, 16 bits, stereo)
- WMA Lossless
- WMA 192 kbps
- WMA 128 kbps
- MP3Pro 144 kbps
- MP3 192 kbps
- MP3 128 kbps
- Apple Lossless
- AAC 192 kbps
- AAC 128 kbps

As the difference between the same recording in different formats is very subtle, and does not usually require that the user adjusts the playback gain, we discarded the fact that different file formats were employed on different devices.

2.4. Measurement procedure

The test of each of the 13 available devices has been performed as follows.

An Ambassador binaural dummy head was employed. This dummy head is compliant with IEC 60959, and is specifically manufactured for testing "internal" hearing aids.

The devices under test are small portable MP3 players, such as iPods or similar devices, mostly equipped with ear buds (in-ear headphones).

These headphones are very difficult to measure with good reproducibility, as their response is very sensitive to the coupling with the ears. Although the dummy head employed is equipped with realistic silicon moulds of pinnae and ear ducts, the mounting of the ear buds revealed to be critical, and caused some evident measurement errors.

However, each device was measured 5 times, dismounting and remounting the headphones each time, as recommended by the EN 50332 standard. Averaging the result of the 5 measurements, the "mounting error" is reasonably reduced.

The volume control of the player was left untouched since the last usage from the owner of the device, and this is considered to be representative, statistically, of the real way in which these devices are used. No attempt was made to push the gain to the maximum possible (as mandated by EN 50332), so these results are not significant for discriminating "dangerous" devices from "safe" devices.

The headphones of each device were carefully inserted in the soft rubber pinnae of the dummy head, as shown in the following figures:

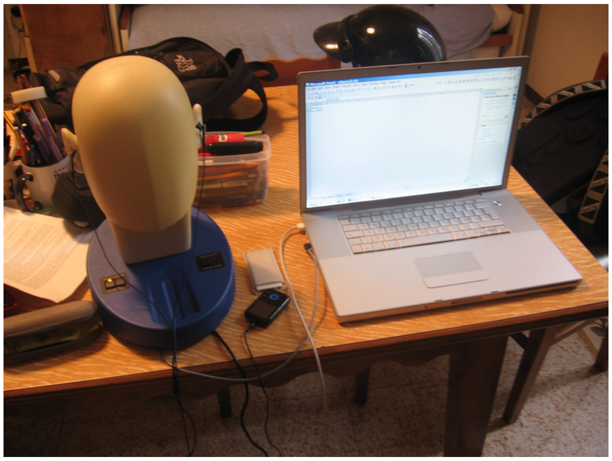

Figure 5 Equipment

Figure 6 Ear bud inserted in the pinna

The stereo output of the Ambassador dummy head are already pre-amplified at “Line” level, so it has been possible to connect it directly to the “Line In” input of a Mac book Pro laptop computer.

The microphones have been calibrated, removing the pinna, and inserting over the capsule a Bruel & Kjaer type 4100 reference sound source, which provides a pure tone at the frequency of 1 kHz and with an RMS sound pressure level of 94 dB (1 Pa).

The calibration signal was employed for forcing the calibration of the SpectraRTA program, as shown here:

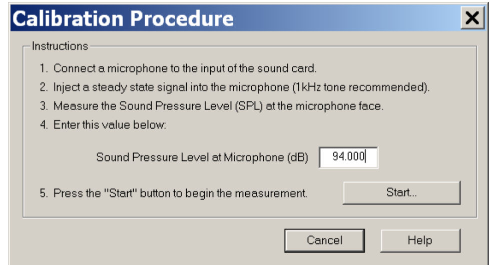

Figure 7 Calibration of SpectraRTA

However, it is also necessary to correct for the frequency response of this specific Head and Torso Simulator. The manufacturer does not provide a suitable free-field frequency response for the Ambassador dummy head. So it was necessary to employ the results of anechoic impulse response measurements which had been previously performed on this specific dummy head at the anechoic chamber of Winterthur (Switzerland), kindly made available by Rieter Automotive.

The following figure shows the resulting free-field average frequency response.

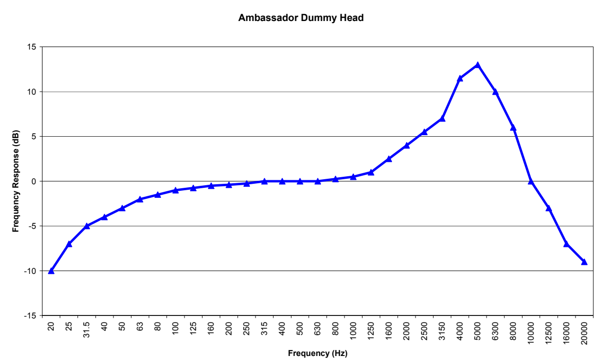

Figure 8 Free-field frequency response of Ambassador

SpectraRTA already provides the capability of correcting for the frequency response of the microphones employed, so the compensation of the frequency response of the Ambassador dummy head did not require any effort.

SpectraRTA was configured for measuring a linearly-averaged spectrum in 1/3 octave bands, averaging the signal of both channels (ears), and computing an unweighted spectrum and an A-weighted wideband value. Each test signals was 60 s long, but the measurement time was set 30 s, leaving 20s at beginning for allowing the device to stabilize before starting the measurement.

As per EN 50332, the measurements were repeated five times, removing and reinserting the headphones each time. However for ensuring a better correlation between the results and in order to minimize the measurement time, we used the same headphone position with both test signals (IEC and MUSIC). The headphone was inserted, then the two signals were measured and then the headphones were removed and reinserted. Each MP3 player played first the IEC programme simulation noise for one minute, with 30 seconds of it being measured and averaged using Spectra RTA, then it did the same with the other test signal.

To ensure that no silence was included in the measurement, the test signal was started before the measurement and it was stopped after the measurement was ended. A picture of each headphone position was taken, along with a picture of each device. The following figure show some of the 13 devices under test:

Figure 9 - Some of the devices under test

3. RESULTS

For each device under test it was possible to obtain two values of the "exposure sound pressure level": the first based on the IEC programme test signal, the second on the MUSIC test signal. The following table show the results, in terms of average SPL +/ the standard deviation.

Table 1 – results of the SPL measurements

Player	IEC	Std.Dev.	MUSIC	Std.Dev.
Napa	74.2	3.1	74.2	2.7
Ipod_jacopo	96.8	2.7	94.7	1.8
Ipod_Bonach	96.2	3.2	96.4	3.7
Zen_Furla	95.7	6.0	95.1	5.7
Ipod_Ganda	91.0	2.6	90.9	2.6
Ipod_Pater	103.9	1.4	103.4	0.8
Packard_Giovati	60.2	4.3	62.0	3.2
Usb_Schianchi	78.4	1.3	77.8	2.6
Archos_Gio	85.2	1.2	85.7	1.2
Ipod_Marianna	87.4	5.9	88.0	6.0
mp4_Tommaso	76.0	3.2	75.2	2.9
Ipod_Gabriele	81.4	3.6	80.5	4.1
Usb_Pater	85.5	1.1	85.8	1.0

It can be seen that only one of the devices tested produced an SPL larger than 100 dB (A): it was an iPOD Video 30 GB, but it was equipped with after-market Sennheiser headphones. It must be said that iPODs sold on the European market have an internal limitation of the playback gain, which is designed for avoiding levels in excess of 100 dB with the original headphones. But, when the headphones are changed with more efficient ones, this internal limitation becomes insufficient for avoiding exceeding the prescribed limit.

The standard deviation of the measurements performed on each device is usually reasonably limited, in the range of 3 to 4 dB. Instead, the differences among the devices tested are very large. One device was producing very feeble levels (60 dBA), another, as already pointed out, was well in excess than 100 dB(A). The following figure display graphically such a dispersion:

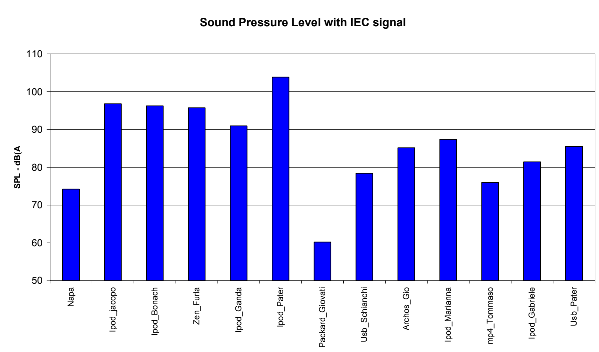

Figure 10 – Dispersion of the results

On the other hand, there is substantially no effect of the test signals: the SPL values obtained with the IEC programme test signal are always within +/- 2.0 dB of the values obtained with the MUSIC test signal. It can be concluded that, although the IEC revealed to be quite different from the real spectrum of modern music, the assessment of noise exposure levels performed employing the obsolete IEC spectrum is still reasonable, considering the other sources of errors, of greater magnitude, encountered.

Finally, it was attempted to obtain an estimate of the frequency response of the devices under test. This was done subtracting the spectrum of the IEC programme signal from the measured spectra (obtained with the IEC test signal, obviously).

The following picture show the frequency response of all the devices under test, normalized at 0 dB at 1 kHz.

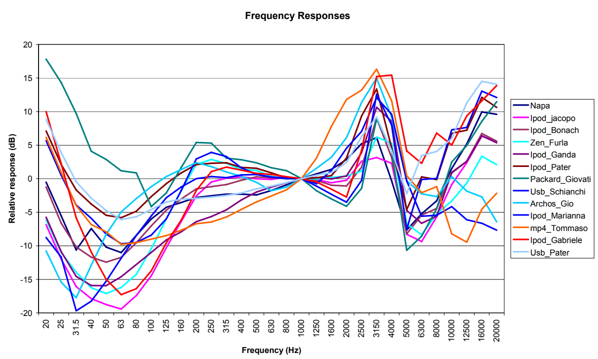

Figure 11 – Frequency response curves

Despite the obvious dispersion among the frequency responses of the various devices, it appears evident that at 3150 Hz a strong ear duct resonance is present, due to the air trapped behind the ear bud. Looking at the free-field frequency response of the Ambassador dummy head (fig. 7), the peak in the frequency response was instead at 5 kHz, corresponding to the "dip" in the curves of fig. 11.

So here we are in presence of an evident artifact: it is wrong t employ the free-field frequency response of the dummy head for correcting the recorded signals, as the free-field response does not take into account the modification of the ear duct resonance occurring when an ear bud is inserted in the pinna. This can be seen as a severe inconsistency of the current EN 50332 standard.

If this test had to be repeated, hence, instead of employing the free-field response of the dummy head for correcting the signals captured from the in-ear microphone, it could be more advisable to employ a diffuse-field response (which is usually smoother), or, provided that the dummy head is equipped with his own internal filtering network, rely on it and not apply any additional correction.

3.1. Analysis of human exposure

The results found in the previous section are quite alarming, as a significant number of the devices under tests were found set for very high playback levels, 90 dB(A) or more.

It should be considered that, in terms of assessment of noise-induced health risk, usually a "safe" value is considered to be a daily exposure of 8 h at 80 dB(A). This is the threshold under which no action has to be performed, according to the EC directive on noise exposure at the workplace.

Whenever higher SPL values are present, the duration of the exposure should be reduced, in order of keeping the same daily "noise dose". An energetic equivalence principle is assumed, which means that the exposure should be reduced at 4h for an SPL of 83 dB(A), to 2h for an SPL of 86 dB(A), and so on.

So, for each of the devices under test, it was computed what is the maximum time allowed daily for employing it for listening to music, as shown in the following table:

Table 2 – maximum allowed daily usage time

Player	Time (hh:mm)
Napa	06:13
Ipod_jacopo	00:10
Ipod_Bonach	00:11
Zen_Furla	00:12
Ipod_Ganda	00:38
Ipod_Pater	00:01
Packard_Giovati	No Limit
Usb_Schianchi	11:30
Archos_Gio	02:26
Ipod_Marianna	01:27
mp4_Tommaso	20:11
Ipod_Gabriele	05:46
Usb_Pater	02:14

It can be seen as for 5 of the 13 devices the time limit is well below 1h, meaning that in reality the owners of these devices are probably exposing themselves to a daily dose well in excess of the safety limit, as most users declared an average usage for 1h to 2h hours.

However, a proper assessment of the real risk could only be done by monitoring for the whole day the noise exposure of the students, and taking into account also the other causes of high sound pressure levels which are part of the life of a teenager: videogames, motorcycles, cinema, discos, sports, etc…

The data obtained in this preliminary work, indeed, suggest that the usage of personal audio players can contribute significantly to the daily noise dose, and can result, on the long term, in severe risk of hearing loss and of other noise-exposure induced illness.

It appears necessary that these devices are designed and calibrated in such a way that they cannot generate such high sound pressure levels, and that more severe regulamentations are enforced. We cannot wait 10 or 20 years, for later discovering that entire generations of the population are suffering of severe hearing problems due to over-exposition in their teen age. Hearing loss is already the prime cause of work-induced illness in Europe, causing unacceptable costs to the public health and insurance systems.

A lot of money has been spent for reducing the noise at the workplace, but this will be wasted if we allow our youngsters to be over-exposed for years due to the usage of personal digital audio players capable of dangerous levels.

4. REFERENCES

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