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Supra and intra-aural earphones: a study of output intensity and hearing levels of their users

Fones de ouvido supra-aurais e intra-aurais: um estudo das saídas de intensidade e da audição de seus usuários

Maria de Fátima Ferreira de Oliveira[1], Kelly Cristina Lira de Andrade[1], Aline Tenório Lins Carnaúba[1], Gabriella de Oliveira Peixoto[1], Pedro de Lemos Menezes[1]

ABSTRACT

Introduction: Hearing loss caused by the improper use of amplifying devices such as smartphones has been growing rapidly. **Purpose:** Measure and analyze the maximum and equivalent output intensities of supra-aural and intra-aural headphones, compare the adjusted intensities and correlate time and intensity of use, average frequencies of 500 Hz, 1000 Hz and 2000 Hz and the speech recognition threshold. **Methods:** The sample consisted of 20 subjects from both sexes, between the age of 16 and 27 years. The results were analyzed per ear, totaling 40 ears. The following procedures were adopted: questionnaire application, inspection of the ear canal, tonal and vocal audiometry, impedance testing and assessment of output intensities of supra-aural and intra-aural headphones. **Results:** Supra-aural headphones have significantly higher equivalent and maximum output intensities compared to their intra-aural counterparts. When adjusted maximum intensities were compared, it was found that intra-aural headphone users used significantly higher equivalent and maximum output intensities than supra-aural headphones users, showing a moderate correlation between time of use and daily use at a frequency of 3000 Hz. **Conclusion:** During the playing of a song, supra-aural headphones have outputs with greater equivalent and maximum intensities than intra-aural headphones. Intra-aural headphone users use higher equivalent and maximum output intensities than users of supra-aural headphones. Subjects that listen to music often do so for less time during the day, but at greater intensity.

Keywords: Audiology; Hearing loss; Audiometry; Noise; Music

RESUMO

Introdução: A perda auditiva ocasionada pelo uso inadequado de aparelhos amplificadores, como s*martphones*, vem crescendo rapidamente. **Objetivo:** Mensurar e analisar as intensidades máximas e equivalentes de saída dos fones supra-aurais e intra-aurais, comparar as intensidades equivalentes e máximas ajustadas entre os dois tipos de fones e correlacionar o tempo de uso, a intensidade de uso e a média de 500 Hz, 1000 Hz e 2000 Hz e o limiar de reconhecimento de fala. **Métodos:** A amostra foi composta por 20 sujeitos de ambos os gêneros, com faixa etária de 16 a 27 anos. As análises dos resultados foram realizadas por orelha, totalizando 40 orelhas. Os procedimentos adotados foram: aplicação de questionário, inspeção do conduto auditivo externo, audiometria tonal e vocal, imitanciometria e avaliação das intensidades de saída dos fones supra-aurais e intra-aurais. **Resultados:** Os fones supra-aurais possuíam saídas com intensidades equivalentes e máximas significativamente maiores que os intra-aurais. Quando comparadas as intensidades máximas ajustadas, constatou-se que os usuários de fones intra-aurais utilizaram saídas com intensidades equivalentes e máximas significativamente maiores que os usuários de fones supra-aurais, observando-se uma correlação de média força entre o tempo de uso e o uso diário, na frequência isolada de 3000 Hz. **Conclusão:** Os fones supra-aurais possuem saídas com intensidades equivalentes e máximas maiores que os fones intra-aurais, na execução de uma música. Os usuários de fones intra-aurais utilizam saídas com intensidades equivalentes e máximas maiores que os usuários de fones supra-aurais. Os sujeitos que ouvem música com mais frequência, as ouvem por menos tempo ao longo do dia, porém, com a maior intensidade.

Palavras-chave: Audiologia; Perda auditiva; Audiometria; Ruído; Música

Study conducted at Universidade Estadual de Ciências da Saúde de Alagoas – UNCISAL – Maceió (AL), Brazil.
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INTRODUCTION

New life habits are characterized by the increasing use of listening devices with headphones designed specifically for children, teenagers and adults. Adolescents are frequently exposed to high-intensity amplified music, especially in their leisure activities. Music, in general a pleasant sound that produces pleasurable feelings, can become a source of sound pollution, depending on its intensity and the manner in which it is listened to[1]. Listening to music is healthy, but the habit of listening to it at high intensities has become so natural, that few people are aware of the real dangers it can conceal[2].

Since the emergence of the Walkman in 1979, technological evolution has contributed to the current popularity of portable listening devices. In addition to their miniaturization, there has also been a significant increase in storage capacity and battery life, factors that lead users to listen to music for several consecutive hours, often at a far-from-advisable intensity[3].

Hearing loss caused by the improper use of amplifying devices, such as smartphones and MP3/MP4 players, has increased sharply among children and teenagers. These devices can reach up to 130 decibels (dB) of sound intensity[4].

Depending on the intensity and duration of exposure, loud sounds may lead to a temporary or permanent rise in hearing thresholds, primarily at frequencies of 3000 Hz, 4000 Hz and 6000 Hz. Continuous exposure to high sound pressure levels may prompt an increase in hearing loss at these frequencies, and over time, extend to low, midrange and high frequencies. Given that hearing loss induced by high sound pressure levels is gradual, it is estimated that mild hearing loss in adolescents could reach severe levels in old age[5].

Since sound pressure levels related to leisure activities are not regulated in Brazil, occupational noise exposure patterns have been used as parameter. The first annex of Regulatory Guideline 15 (NR 15) stipulates a maximum of 85 dB (A) for an eight-hour exposure to continuous or intermittent noise[6]. According to this guideline, when noise is 115 dB(A), the exposure time allowed is seven minutes.

Devices currently on the market include supra-aural headphones, which are external, intra-aural headphones, made of rigid material and used in the forward-most part of the external acoustic meatus, and intra-aural headphones, which are fitted with silicone tips, making them more flexible. It is believed that the deeper the insertion of these headphones into the external ear canal, the greater the sound amplification, since there is a change in volume in the outer ear. Thus, different headphones provide different amplifications, since they cause variations in volume and resonance, depending on the degree of insertion[4].

The aims of this study were to measure and analyze equivalent output intensities of supra-aural and intra-aural headphones during the playing of a song, analyze the maximum output intensities of supra-aural and intra-aural headphones during the playing of a song, compare user-adjusted equivalent intensities between the two types of headphones used, compare user-adjusted maximum equivalent intensities between the two types of headphones and correlate the time of use, intensity of use and auditory parameters analyzed (average frequencies of 500 Hz, 1000 Hz and 2000 Hz and the speech recognition threshold – SRT).

METHODS

This is an analytical, observational cross-sectional study, conducted in a public institution in the city of Maceió, Alagoas state, Brazil. The study was approved by the Research Ethics Committee of the *Universidade Estadual de Ciências da Saúde de Alagoas* (CAAE: nº 45441415.6.0000.5011). The sample consisted of 20 subjects, selected by spontaneous demand after dissemination, and subdivided into two groups: G1 (composed of eight supra-aural headphone users) and G2 (composed of 12 intra-aural headphone users). Analyses of the results were conducted per ear, totaling 40 ears.

Before the start of the field study, the two types of headphones were calibrated, using a Brüel & Kjær 2250 light sound level meter, a Brüel & Kjær 4153 artificial ear with a pre-amplifier, and Brüel & Kjær AO-0440-D-015 triaxial signal cable, adjusted with a contact force of 4.5N. These instruments were calibrated before the tests with a Brüel & Kjær sound level meter calibrator, at a frequency of 1000 Hz at 94 dB (Figure 1).

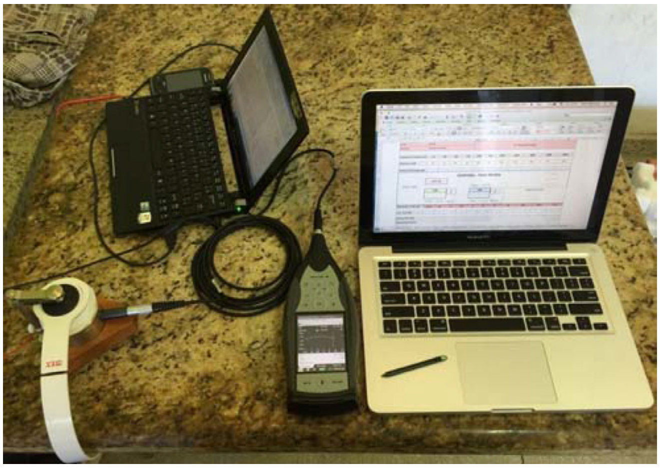

Figure 1. Sound pressure analyzer and artificial ear used to measure headphone sound

Frequency and intensity tests were carried out using 1/3 octave analysis, measured on a dB A-weighting curve (dBA), equivalent (Leq dBA) and maximum levels (Leq Max dBA) and peak equivalent intensity levels SLPpe (LZ, 1000 Hz). Equivalent and maximum intensities were tested during the initial 60 seconds of the song selected, at each of the 18 intensities of the sound system used, at 5% intervals between 15 and 100%. The tests were conducted for both supra-aural and intra-aural headphones, following ISO 389, ISO 8253 and

IEC 644-1 standards (adapted). These tests were compared and analyzed using statistical methods, described in a specific topic.

Next, the procedures were carried out with the study participants. The following inclusion criteria were established: age between 15 and 30 years; normal hearers, that is, hearing thresholds less than or equal to 25 dBNA[7], with inter-ear frequency differences less than or equal to 10 dB; type A tympanogram; ipsilateral acoustic reflexes at frequencies of 1 and 2 kHz and contralateral reflexes at 0.5 kHz, 1 kHz, 2 kHz and 4 kHz; use of intra-aural or supra-aural headphones for at least one hour a day.

The exclusion criteria were individuals with earwax or a foreign body that could hinder visualizing the external auditory canal; those with otoscopic and/or tympanometric alterations suggesting outer ear alterations and/or poor middle ear function; individuals with hearing alterations; ringing in the ear, vertigo, dizziness and other vestibulocochlear alterations; individuals diagnosed with auditory neuropathy spectrum; history of ear surgery; use of ototoxic medications; concomitant use of intra-aural and supra-aural headphones and auditory rest of less than 14 hours.

Initially, the research procedures were explained verbally, after which all the participants gave their informed consent.

Next, a questionnaire was applied (Appendix 1) to screen participants. The instrument made it possible to investigate vestibulocochlear pathologies, previous exposure to environments with high sound pressure levels, the number of hours using the sound equipment with headphones, etc.

After the questionnaire was applied, the following procedures were carried out:

- Inspection of the external auditory canal to determine its integrity and that of the tympanic membrane (Heine® – Mini 3000 otoscope);
- Impedance testing using an AT 235 impedance audiometer to select participants with normal middle ear function. Acoustic reflexes were assessed separately, in each ear, at frequencies of 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz, using the same equipment in the ipsilateral and contralateral modes of the ear assessed. Normal values were considered to be between 70 dB and 100 dB above the hearing threshold at the specific frequency[8].
- Tonal and vocal audiometry, performed using an Interacoustics® AC 33 audiometer to identify tonal and vocal hearing thresholds within normal patterns. The thresholds were determined by applying the psychoacoustic descending method of limits technique with 10-dB steps, and the ascending technique with 5-dB steps, to confirm the responses. Octave frequencies were assessed between 250 Hz and 8000 Hz. The acoustic cabin followed ANSI S3.1 199 recommendations[9]. The examinations were conducted with patients sitting on a chair inside the acoustic cabin. The first ear assessed was randomly selected.

With a view to measuring the output intensity of the headphones, the patients were asked to adjust the volume of a song ("*Pais e Filhos*" by the band Legião Urbana)[10] on the laptop (Infoway® NET W7020) to a level they felt comfortable with for their own hearing threshold, in a silent environment. Headphones similar to those habitually used by the participants were used, namely Samsung® GT-19100 intra-aural and Sony® MDRZX3101P supra-aural headphones.

Statistical analysis

Statistical analysis was carried out using Statistical Package for the Social Sciences (SPSS) software, version 21.0 for Macbook®. The data were presented as tables and graphs of means, standard deviations and confidence intervals. The Shapiro-Wilk normality test was used. The equivalent (Leq dBA) and maximum (Leq Max dBA) output power for each type of headphone were assessed using the Wilcoxon test, since both served as equipment variables. Ages, audiograms and user-adjusted intensities for the different types of headphones were compared applying the Mann U nonparametric test and correlations were established by a bivariate correlation test, with the degree of linear relationship analyzed using Spearman's coefficient. The differences were considered significant for a p-value less than 0.05.

For the tests with headphones, parametric tests were not used since not all the groups were normally distributed.

RESULTS

The sample consisted of 20 volunteers of both sexes, 8 of whom used supra-aural and 12 intra-aural headphones. As stated earlier, the tests were applied individually to each ear, resulting in a study of 40 ears, 16 (40%) with supra-aural and 24 (60%) with intra-aural headphones.

The study participants were aged between 16 and 27 years, with an average of 23 years, standard deviation of 2 years and 59 months. The Mann-Whitney test showed no significant intergroup differences for the audiogram (p=0.90, p=0.50, p=0.65, p=0.25, p=0.52, p=0.23, p=0.90 and p=0.72, respectively, for frequencies of 0.25k, 0.5k, 1k, 2k, 3k, 4k, 6k and 8kHz) or ages (p=0.23). The distribution of average hearing thresholds is described in Figure 2.

In comparisons between equivalent output intensity tests (Leq dBA) of intra-aural and supra-aural headphones during the playing of a song, the Wilcoxon test demonstrated that the supra-aural headphone outputs exhibited significantly higher equivalent intensities than their intra-aural counterparts (p=0.004). The mean, confidence interval and standard deviation values of each group are shown in Table 1.

In the study of maximum equivalent output intensities (Leq Max dBA) of intra-aural and supra-aural headphones, the same test indicated that the latter had significantly higher equivalent output intensities than the former (p=0.002). The

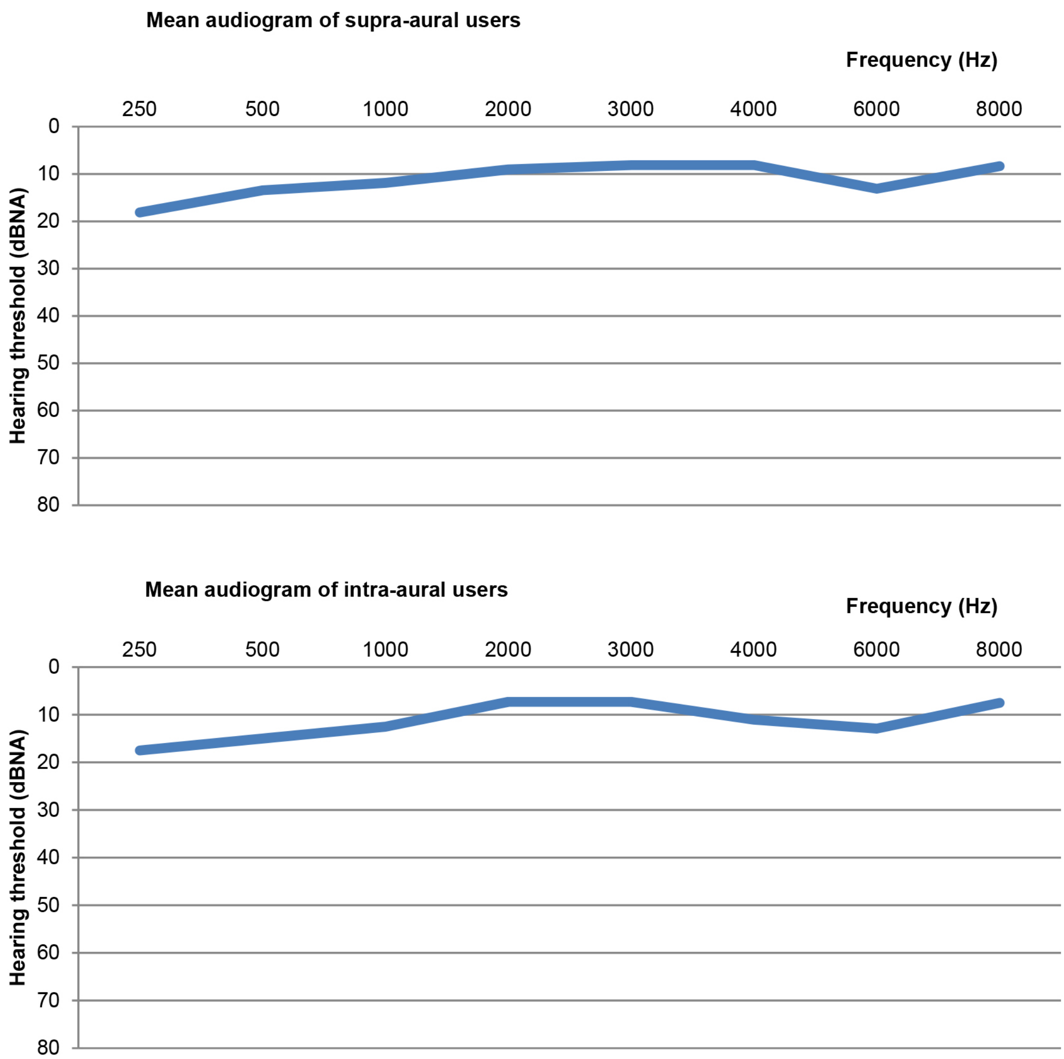

Figure 2. Distribution of the mean hearing thresholds of the two study groups

mean, confidence interval and standard deviation values of each group are described in Table 2.

Tests with human beings preclude the use of parametric tests, since once again, not all groups exhibited normal distribution.

With respect to comparisons of user-adjusted equivalent intensities, between the two types of headphones used, the Mann-Whitney U test showed that intra-aural headphone users preferred outputs with significantly higher equivalent intensities than supra-aural users (p=0.007). The mean, confidence interval and standard deviation values are depicted in Table 3.

In comparisons of user-adjusted maximum equivalent

Table 1. Mean values of equivalent output intensities, confidence interval and standard deviation in supra-aural and intra-aural headphones

Headphone	Mean (dBA)*	Confidence interval (dBA)	Standard deviation (dB)
Supra-aural	82.30	78.37 – 86.24	9.09
Intra-aural	80.96	77.45 – 84.46	8.11

* Wilcoxon test (p=0.002)

Table 2. Mean values of maximum output intensities, confidence interval and standard deviation in supra-aural and intra-aural headphones

Headphone	Mean (dBA)*	Confidence interval (dBA)	Standard deviation (dBA)
Supra-aural	88.22	84.22 – 92.21	9.24
Intra-aural	86.35	83.22 – 89.47	7.23

* Wilcoxon test (p=0.007)

Table 3. Mean values of user-adjusted equivalent output intensities, confidence interval and standard deviation in supra-aural and intra-aural headphones

Phone	Mean (dBA)*	Confidence interval (dBA)	Standard deviation (dBA)
Supra-aural	76.63	74.91 – 78.34	3.22
Intra-aural	83.25	80.30 – 86.20	6.98

* Mann-Whitney test (p=0.010)

intensities, between the two types of headphones used, the same test revealed that intra-aural headphones users opted for outputs with significantly higher maximum equivalent intensities than supra-aural users (p=0.010). The mean, confidence interval and standard deviation values of each group are exhibited in Table 4.

With a view to correlating the total time of headphone use, time of daily use, intensity of headphone use and auditory parameters analyzed (average frequencies of 500 Hz, 1000 Hz and 2000 Hz and SRT), bivariate correlation with the degree of linear relationship observed using Spearman's correlation showed the following:

1. Moderate inverse correlation between total and daily time of use (p=0.02 and r=-0.350). In the present study, the more time subjects listened to music, the less time they used the headphones on a daily basis.
2. Moderate correlation between total time of use and equivalent intensity (p=0.01 and r=0.399). In the present study, the more time subjects listened to music, the stronger the intensity.

The mean, confidence interval and standard deviation values of total time of headphone use, time of daily use, intensity of use, the tritonal mean and SRT are shown in Table 5.

The correlation of these variables with individual frequencies, using bivariate correlation with the degree of linear relationship observed using Spearman's coefficient, demonstrated a moderate correlation between total time of use (experience) and daily use, at a frequency of 3000 Hz (p<0.01 and r=0.44 and r=0.47, respectively). In other words, the greater the experience and daily use, the higher the tendency to an increase in threshold at a frequency of 3000 Hz.

DISCUSSION

In general, headphones available on the market are divided into supra-aural and intra-aural models. Each model exhibits a number of variations, which determine the quality, value and control of the product. The design of the headphones varies according to user preference, but depending on the choice, the subject will be more exposed to high sound pressure levels, which raises the risk of hearing loss.

Intra-aural headphones, which are more discrete, practical and normally less expensive, are currently the most popular. The position of this type of headphone, which is inserted into the external auditory pathway, favors greater intensity levels, since all the sound pressure is conducted to the middle ear[1]. The problem is aggravated when these small headphones do not fit perfectly into the auditory pathways, which allows entry of external sounds, causing the user to raise the volume of the sound device, in order to mask environmental noise.

One of the limitations of this study was to not allow participants to use their own headphones or devices, given that each headphone had a specific format which, in most cases, did not allow coupling in the calibration system or compliance with pertinent ISO and IEC guidelines, especially the supra-aural variety, and each device had its own volume adjustment. For these reasons, we used two models calibrated according to

Table 4. Mean values of user-adjusted maximum output intensities, confidence interval and standard deviation in supra-aural and intra-aural headphones

Headphone	Mean*	Confidence interval*	Standard deviation*
Supra-aural	83.00	81.05 – 84.95	3.65
Intra-aural	88.58	86.00 – 91.17	6.12

* Values expressed in dBA

Table 5. Mean, confidence interval and standard deviation of each variable studied

Variable	Mean	Confidence interval	Standard deviation
Time of use (months)	71.93	61.97 – 81.88	31.13
Daily use (hours)	3.00	2.17 – 3.83	2.60
Intensity (dBA)	80.60	78.49 – 82.71	6.60
Tritonal mean (dBA)	12.38	11.17 – 13.58	3.75
SRT (dBA)	16.13	14.00 – 18.25	6.65

current guidelines and the participants used the sound intensities they normally selected when listening to music.

According to the data analyzed here during the playing of a song whose volume was adjusted by each participant, the equivalent and maximum equivalent output intensities of supra-aural headphones were significantly higher than those of their intra-aural counterparts. The mean maximum equivalent intensity for supra-aural and intra-aural headphones was 88.22 dBA and 86.35 dBA, respectively (p=0.007). With respect to intra-aural headphone users, the study revealed outputs with significantly higher equivalent and maximum equivalent intensities than users of supra-aural headphones. The mean maximum equivalent intensities for intra-aural and supra-aural headphones were 88.58 dBA and 83.00 dBA, respectively. Mean total time of use and daily use were 71 months and 2.602 daily hours, that is, approximately six years and three hours, respectively.

The maximum intensity adjusted by intra-aural headphone users was above the value recommended by NR15 that limits exposure to 85 dB for eight hours a day, which could cause hearing loss in the participants. According to the same guideline, for each 5 dB rise in sound intensity, exposure time should be reduced by half[11]. However, technically, and in line with more recent international guidelines, a 3 dB rise doubles the sound intensity, which reduces exposure time by half[12]. Brazil, however, is one of the few countries that does not adhere to this recommendation. Even though the guideline was created for workplace noise, music can cause similar hearing loss. According to international recommendations, those who use their individual devices with mean maximum equivalent intensities of 88.58 dBA should not be exposed for more than two hours a day. Furthermore, the testing environment was silent, with background noise of around 40 dBA. In practice, background noise is nearly always louder than this. As such, these individuals can listen to music with higher intensities than those found here. These parameters could decrease exposure time to less than three minutes, in accordance with international recommendations[12].

With respect to the subjects' habit of listening to music, the present investigation proved that the longer (in months) that they regularly used headphones, the less time they used them on a daily basis. In other words, users tend to progressively decrease the number of hours they use this equipment.

By contrast, the longer the use, the stronger the intensity of the music. This was a worrisome finding, since, in temporary threshold changes, a situation that normally precedes permanent changes in auditory thresholds, slight intracellular changes take place, such as a decline in the rigidity of stereocilia, which, in turn, reduces the ability of cells to perceive sound energy that previously reached them, thereby altering auditory sensitivity[13,14]. This may explain the rise in intensity due to the continuous use of portable listening devices with individualized headphones. This finding is in contrast with another study, which investigated the audiometric thresholds of users and non-users of portable listening devices and their respective sound pressure levels, in different acoustic environments, correlating them with user complaints, showing that those who used headphones for more than two days a week, did sot for more hours a day[15]. However, the study measured the sound pressure level used in personal music devices in two listening situations: in silence and with background noise.

In relation to the tendency to an increase in threshold at 3000 Hz, when correlating total time of use, time of daily use, intensity of headphone use and the auditory parameters analyzed with the hearing thresholds at isolated frequencies, the results corroborated classic literature studies, which demonstrated that intense sounds can lead to a temporary or permanent rise in hearing thresholds, primarily at frequencies of 3000 Hz, 4000Hz and 6000 Hz[16,17,18,19,20]. Similar results were found by researchers who reported a difference in sound pressure when young people use devices with earbud and in-ear headphones. The study confirmed that, when an in-ear headphone is used, the frequency peak at which the highest sound pressure level occurs is between 3000 Hz and 3600 Hz, and that the sound pressure levels of personal music players were higher when in-ear headphones were used, which would increase the risk of hearing loss[4].

A recent study showed that in workplace environments, research on hearing loss induced by high sound pressure levels has been losing ground to investigations of the connection between hearing loss and the use of sound devices with different types of headphones. The concern expressed in the study is due to the analysis of environments where young people usually meet, such as bars, night clubs, and shows, among others, where the sound levels are generally above 100 dBA[21]. In portable listening devices with headphones, this intensity can reach up to 130 dBA[4,22].

Studies in this area should be increasingly encouraged, since not only are sound characteristics important for developing hearing loss, but also individual susceptibility, which is greater in young people[23], the main users of headphones at high intensities, especially when listening to music.

Given the importance of the issue, already characterized as a significant social and public health problem[24], a new concept has been emphasized by researchers, namely music-induced hearing loss (MIHL). Since there is no specific safe standard for exposure to non-occupational noise, prevention through hearing conservation programs may be the only alternative to achieve behavioral changes, by showing the relationship between hearing and MIHL.

CONCLUSION

Supra-aural headphones have outputs with higher equivalent and maximum equivalent intensities when a song is being played. In addition, intra-aural headphone owners use outputs with higher equivalent and maximum equivalent intensities than their supra-aural counterparts. It was also observed that subjects who listen to music more often, do so for less time during the day, but at a greater intensity. Finally, the more the total time of use and the longer the time of daily use, the greater the tendency for an increase in threshold, at a frequency of 3000 Hz.

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Appendix 1. Questionnaire

I. Registration chart nº

0	1	2	3	4	5	6
0	1	2	3	4	5	6

Date: ______________________________ Date of birth: ______________________________ Sex: F ( ) M ( )
Telephone: ______________________________ E-mail: ______________________________
Address: ____

II. Information:

1) Types of headphones used:

Intra-aural headphone ( )

Supra-aural headphone ( )

Intra-aural and supra-aural ( )

2) On average, how long do you use headphones per day? ______________________________

3) History of ear surgery

Yes ( ) No ( )

Obs:______________________________

4) Subjects with hereditary cases of deafness in second-degree relatives:

Yes ( ) No ( )

Obs:______________________________

5) Use of ototoxic medication:

Yes ( ) No ( )

Obs:______________________________

6) Auditory rest of at least 14 hours:

Yes ( ) No( )

Obs:______________________________

7) Presents with:

( ) Vertigo

( ) Dizziness

( ) Other vestibulocochlear changes

8) Auditory complaints:

Hearing loss? ( ) Yes ( ) No

Obs:______________________________

Ringing? ( ) Yes ( ) No

Obs:______________________________

Earache? ( ) Yes ( ) No

Obs:______________________________

Plugged-up feeling in the ear? ( ) Yes ( ) No

Obs:______________________________

Discomfort from high-intensity sounds? ( ) Yes ( ) No

Obs:______________________________

History of middle ear infection? ( ) Yes ( ) No

More than three infections in the current year? ( ) Yes ( ) No

9) Exposure to occupational noise? ( ) Yes ( ) No

Works or has worked in a noisy environment? ( ) Yes ( ) No

If yes, for how long?______________________________

10) Exposure to leisure noise? ( ) Yes ( ) No

11) Has undergone chemotherapy? ( ) Yes ( ) No