Pure-tone Audiogram
Measuring Auditory Sensitivity over the Age

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Abstract: In this study a pure tone audiogram was developed under the Matlab® mathematical software. Audiogram measurements were performed to 35 subjects belonging to the female and male and aged between 10 and 88 years old. Some of the subjects with more advanced age had hearing problems over the course of age, however, none of them was carrying any type of hearing aid. The threshold of the Sound Pressure Level (SPL) was recorded under 12 pure tones between 125 Hz and 15 kHz. The developed pure-tone audiogram confirmed its ability to produce auditory brainstem responses (ABRs). Statistical analysis of the SPL threshold shows no differences between genders and confirms the correlation between age and loss of sensitivity, more accentuated for higher frequency tones. A strong loss of sensitivity was observed after the decade of 60 years old.

1 INTRODUCTION

The ear is a receiver associated with the procurement, conduct, modification, amplification and analysis of sound waves. The sound waves are due to molecular vibrations in the air and characterized by a given frequency and a given intensity.

At present there are some problems associated with normal operation of the ear which may result in a hearing impairment. Deafness, in particular, is one of the most common symptoms around the world, reaching all ages, from newborns to the elderly, through all the existing races, both gender, with a huge response from the point of view of language and communication, including, family, cultural, professional, emotional and even psychological, with large varied causes (Fransen et al., 2003).

The measure of hearing loss is performed by an audiogram that submit the subject to stimuli with different energy or amplitude and records the threshold of energy necessary to be perceived by subjects. However, the hearing sensitivity varies along the frequency. The human hearing apparatus is more sensitive of the bandwidth between 1 and 5kHz and less sensitive for frequencies below 100 Hz and above 10 kHz.

The literature refer different types of stimuli used in audiograms, such as clicks, noise masking and recorded sounds (Stapells and Oates, 1997). Considering a flat cochlear hearing loss a stimulus of 1000 Hz filtered clicks was also used (Conijn et al., 1990). But the pure tone with different frequencies also has been used by Stapells and Oates, (Stapells and Oates, 1997).

In this context, we propose small pack software to produce the pure tone waves and a program for easily submit the subject to the audiogram test searching for the threshold of energy of the sound wave to be listen to. We also present the results of several subjects and its analysis along the age and gender considering always the different frequency ranges.

2 SOUND AND HEARING

The sine wave, which is used in this work are sound waves that have only one frequency component. Therefore a sound with the shape of a sine is known as a pure tone.

In relation to sound waves, they are associated with changes in pressure called sound pressure and is commonly expressed as Sound Pressure Level (SPL) and is measured in decibel (dB). Sound waves have wavelengths or frequencies of sound, measured

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in cycles per second or Hertz (Hz).

The human ear is sensitive to sound frequencies between 20 Hz and 20 kHz. The frequencies below 20 Hz are called infra-sound, whilst for frequencies over 20 kHz, are called the ultrasound (often used in medicine, more precisely on ultrasound). The equation 1 presents the measure of the SPL in dB as a relation between the pressure (P) and the reference pressure (P_0). This reference corresponds to the threshold of hearing for young persons (aged from 18 to 25 year) at the pure tone frequency of 1000 Hz. This reference corresponds to 20 µPa. For a sound of pressure P equal to P_0 the SPL is 0 dB.

$$SPL = 20\log_{10}\left(\frac{P}{P_0}\right) \quad \text{(dB)} \qquad (1)$$

Fig. 1, represents the relation between SPL over the frequency, and pressure measurement in dB causing the same sense of sound volume in young individuals, in the presence of pure tones (ISO 226:2003).

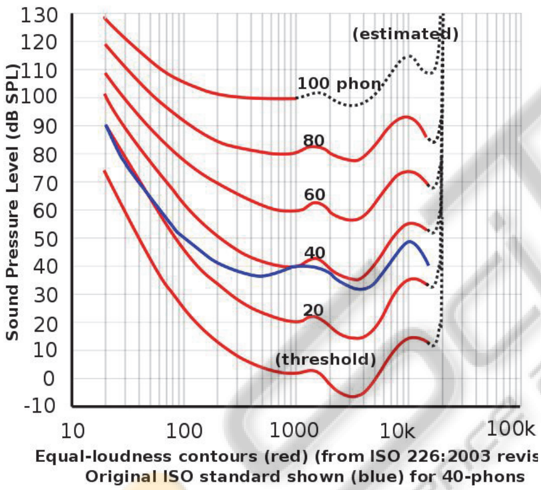

Figure 1: Equal-loudness contour.

3 AUDIOGRAM

This work has focused on measuring the auditory sensitivity along frequency and over the years. For this purpose it was developed an audiogram in software using the mathematical software MATLAB®.

The objectives was measuring the threshold of hearing at 12 different frequencies, ranging from 125Hz down to the 15000Hz, performing the graphic corresponding to the relation frequency / amplitude similarly as the graph presented in Fig.1.

For each frequency a pure tone wave produced by a pure sine wave is created with initial amplitude. Then, the amplitude is gradually adjusted until the subject couldn't perceive sound. The last amplitude is registered and converted to SPL in dB.

A simple program as developed to produce the pure tones along the selected frequencies to be used during the audiogram test. The program intends to facilitate the task of selecting the SPL to be presented to the subject until find the threshold of hearing.

No modulation of amplitude was performed in contrast with the work presented by Canale in (Canale et al., 2006). The program asks for the SPL, then converts the SPL in dB to a linear scale and produces a 2 second long sine wave signal with the frequency and the amplitude introduced by the user. The signal is sent to the audio system to be presented to the subject. The subject should inform if the sound was listen in an interactive way to record the threshold of SPL. The procedure should be repeated for every frequency tone.

The tests were performed with 35 subjects belonging to the female and male gender, aged between 10 and 88 years. Some subjects with more advanced age had hearing problems over the course of age, however, none of them was carrying any type of hearing aid. Importantly, all measures were performed on privileged and quite rooms and with a good sound isolation. The subjects were always placed in front of the computer. The measures were made on the same computer, so this way all the tests were performed with the same consistency in the magnitude of sound waves. Therefore there were no significant changes in the conditions to collect data along subject.

The absolute SPL presented to the subject cannot be determined once the sound card of the computer has an unknown amplification. In order to deal is this situation the value of 1 dB was used as a reference for the threshold of hearing at 125 Hz. We assumed that the audio system of the computer have an equally gain along the frequency range (the frequency response of the computer audio system must be measured and considered in future developments). Therefore the absolute values presented in following section cannot be compared with the absolute values of Fig 1, only the variation of sensitivity along frequencies can be compared, by the shape of the curves of sensitivity.

The same volume level in the computer was kept during all measures.

4 RESULTS

First a comparison of each subject within his decade age was performed for the decades of tens to decade of eighties. Then a comparison between the averages of subject of each decade is presented in Fig. 2. The figure presents the average minimum SPL for each frequency perceived by the subject of each decade. As higher is the curve more SPL in need to be perceived by listener that means less sensitivity. Therefore, a higher value of SPL in the graphic may represent a hearing loss at that frequency. Anyhow, the variation of sensitivity along frequency as presented in Fig. 1 has to be considered normal.

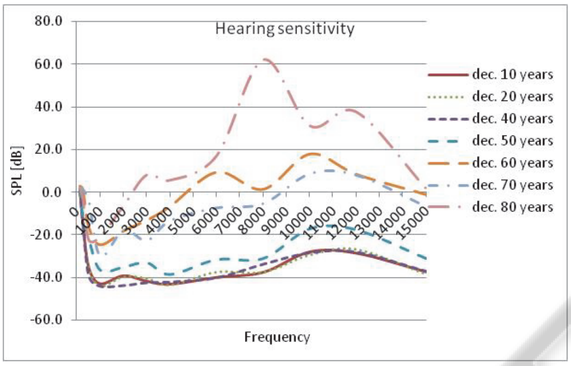

Figure 2: Hearing sensitivity of each decade.

The decades with lower SPL threshold are the first four lower decades, ie concerning the decades 10, 20, 40, and finally concerning the decade at 50 years. These first four decades have a hearing sensitivity pattern similar to the pattern presented in Figure 1, meaning that the eventual hearing loss may not be significant. Moreover, the latest age corresponding to the 60, 70 and 80 decades illustrate that the higher decades are correlated with a significant loss of sensitivity. Thus, it is recommended to the people belonging to this ages and who have very significant hearing loss, the possible use of hearing aids in order to aid the process of hearing (Bento et al., 2010), (Cheng et al., 2011).

5 STATISTICAL ANALYSIS OF RESULTS

For all results of inferential analysis a 5% of significance level was assumed.

Table 1 lists some characteristics of the subjects. The original sample consisted in 35 subjects, 77,1% female and 22,9% male. The 6 subjects with clinical diagnosis of hearing pathology 83,3% are female, and those who are not a clinical diagnosis of the pathology 75,9% are female.

Table 1: General Characteristics of Sample (N=35).

subjects	No.	%
Gender		
Female	27	77,1
Male	8	22,9
Age		
Decade 10	7	20,0
Decade 20	7	20,0
Decade 30	1	2,9
Decade 40	5	14,3
Decade 50	3	8,6
Decade 60	2	5,7
Decade 70	5	14,3
Decade 80	5	14,3
Clinical diagnosis of Hearing pathology		
With	6	17,1
Without	29	82,9

In order to evaluate differences of SPL among the eight age decades in each Frequency tones, a Kruskal-Wallis test was conducted. The Kruskal-Wallis Test is the nonparametric test equivalent to the one-way ANOVA and is used when the assumption of the parametric test have been too grossly violated (Green and Salkind, 2008). It is used to test the null hypothesis that all populations have identical distribution functions against the alternative hypothesis that at least two of the samples differ only with respect to location (median), if at all. Chi-square and p-value have been used for the comparison. Results are not statistically significant for the frequency tones of SPL at 125 and 500 Hz (p-value>0.05), it indicates that the groups are not different from the others. The results of the analysis for the remaining frequency tones indicates that there is a significant difference in the SPL medians, it is the same that at least one of the groups is different from the others. It can therefore be concluded that there are differences in the SPL threshold at frequency tones among the group age decades.

To evaluate if the median performance of the SPL along the frequency tones differ for female and male, the pairwise comparisons was conducted using the Mann-Whitney U test (nonparametric test), which yields identical results with the Kruskal-Wallis test for two independent samples (Green and Salkind, 2008). Based on the results at the α=0.05 level of significance, the results does not provide statistically significant evidence of a difference between female and male in median of SPL at all frequency tones used (p-value>0.05).

The Pearson's correlation was used to find a correlation between the variables Age decades and SPL threshold at the frequency tones. According to the provided results it is possible to say that the strength association between these two continuous variables is very high and that the correlation coefficient is very highly significantly different from zero (p-value<0.05). For all results produced were obtained positive coefficients of correlation which indicate that for every frequency tones the older age higher is the SPL threshold of hearing. Additionally, as higher is the frequency tone higher is the Pearson correlation meaning that for higher frequencies more correlated are the decade ages with SPL threshold. This last observation leads to the conclusion that the lost of sensitivity along age is more effective for higher frequency tones.

In order to complete the inferential analysis and see if there is an association between the variables Clinical Diagnosis of Hearing Pathology and Age Decade Group (considering two groups: more than 50 years and less than or equal to 50 years), the Fisher's exact test took place, recommended when we have two nominal variables (Green and Salkind, 2008). The result indicated that the null hypothesis can be rejected; so it was possible to say that the variables are associated.

6 CONCLUSIONS

A pure tone computer software device to produce auditory brainstem responses was developed and used to measure the threshold of SPL perceived by 35 subjects in a scale a different frequency tones. A small group of six individuals had a clinical diagnosis of hearing pathology, but none of them use any hearing device.

Despite the small number of individuals used in the test it was clear that the lost of sensitivity was higher in older individuals and became more effective after the decade of 60 years old.

A statistical analysis using SPSS software was performed. It may be concluded that no significant differences exist in the frequency tones of 125 and 500 Hz, but there are significant differences in other frequency tones (250 Hz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, 8 kHz, 10 kHz, 12 kHz and 15 kHz). There are no statistically significant evidence of a difference between female and male of SPL at all frequency tones used. It was also concluded that there is a high correlation between SPL threshold and age within all frequency tones. Despite this obvious conclusion it was confirmed for all frequency tones. The statistical analysis also leads us to the conclusion that as higher is the frequency tone more correlation there is between sensitivity loss and age.

Finally, the statistical analysis confirmed a high correlation between subjects with clinical diagnosis of hearing loss and the threshold of SPL.

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