Remote Evaluation of Impulse Signals in Refrigerators Using Psychophysical Models

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Abstract
Impulsive sound events are characterized by their short duration, high amplitude, and wide spectral spread. In the industry, these events are classified as undesirable noise and have been gaining the attention of manufacturers. In rotating machines, automobiles, and refrigeration systems, these noises occur in an anomalous and unplanned manner, generating a lot of discomfort and loss of customer reliability with manufacturers. In a sample of 247 individuals, the differential threshold of refrigerator impulsive signals was remotely measured using the internet. Thus, the threshold of impulsive signals for different amplitudes, duration times, and frequency ranges was estimated. The differential threshold was obtained by the adaptative staircase method. Sinusoidal signals were synthesized with frequencies between 500 Hz and 3000 Hz conducted randomly for each user. Therefore, it was possible to compare the prominence obtained between the sessions. Also, The results showed that individuals are more sensitive to signals with higher frequencies, with a smaller observable difference. Women had lower thresholds compared to men, as well as specialists, who had better results compared to laymen. In addition, older people had higher thresholds.

Keywords: Impulsive signals; Psychophysical methods; Differential threshold; Internet listening test.

1 Introduction

Human hearing is particularly sensitive to transient sound characteristics, such as impulsive content [1]. However, there is no specific metric for analyzing annoyance in impulsive signals, much less for impulsive signals from refrigerators [2]. To build a metric it is necessary to know the relationship between stimulus intensity and stimulus response [3]. A good way to obtain this information is through the determination of thresholds.

Currently, there are few studies of remote threshold assessments. There are many precautions regarding the instrumentation and test reproduction environment. A controlled environment, with low background noise, as well as a sound reproduction system that presents little distortion and flat response are necessary elements to obtain good results [4]. Allied to this, impulsive signals require more care, as they have short duration increases in amplitude, occurring at high rates of changes [5]. However, face-to-face testing has become impractical due to the COVID-19 pandemic, with the remote form being the only possible means for constructing and performing threshold tests.

One of the most common ways to determine thresholds to present several levels of the stimulus and determine the desired value from a derived psychometric function [3, 6]. However, although it is possible to obtain good results, the tests tend to be time-consuming and repetitive, being impractical in most cases. A good alternative to circumvent problems with the duration of the tests is to use an adaptive staircase method, in which the stimulus adjusts according to the subject's response history [7]. Stimulus levels are adjusted based on pre-established rules and the test ends when the stimuli approximate the subject's threshold, which makes the method very efficient and with low computational cost [8].

2 Experimental Methodology

2.1 Signals, Recording and Processing

Refrigerators operating in steady-state and transient regimes were recorded in a semi-anechoic camera with the aid of an artificial head (HATS) positioned 1.60 meters from the floor and 1 meter away from the refrigerator, as shown in Figure 1. The acquired signals were filtered and subsequently divided into two categories: reference signals and masking signals. For the reference signals, impulsive noises typical of refrigerators were recorded. Masking signals were obtained by recording the refrigerator in steady state.

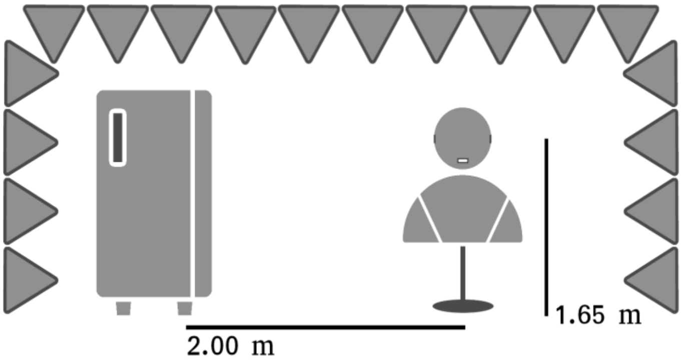

Figure 1 – Measurement setup used in recording reference signals and masking signals.

The reference signals were recorded for 3 seconds. However, the duration of the impulsive noise was approximately 135 milliseconds. After acquisition, the signals were filtered with second order filters (bandpass) tuned to frequencies of 500 Hz, 1000 Hz and 3000 Hz, equivalent to the critical bands of 5, 9 and 16, respectively. Finally, zero padding was applied in the intervals that precede and follow the impulsive noise. Processing and reference signals are shown in Figures 2 and 3, respectively.

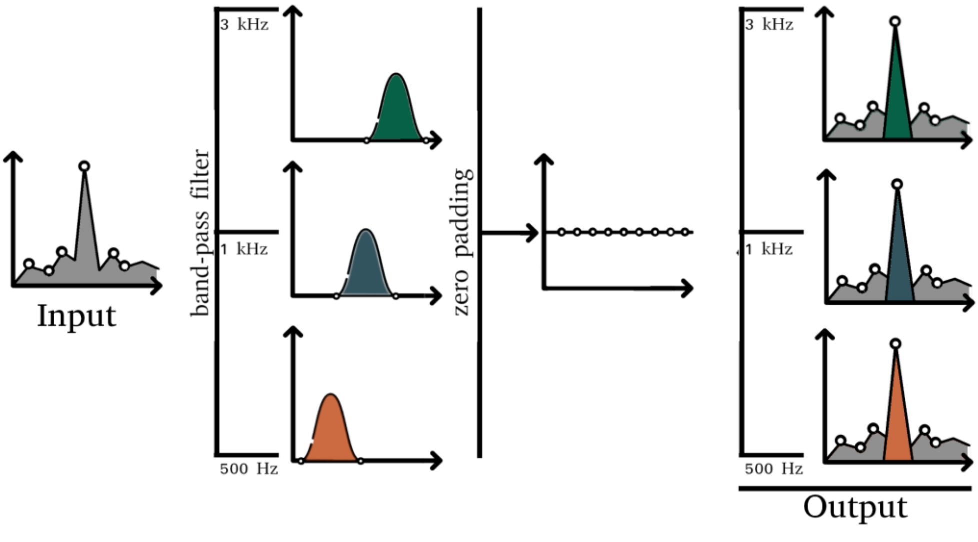

Figure 2 – Signal processing used for reference signals.

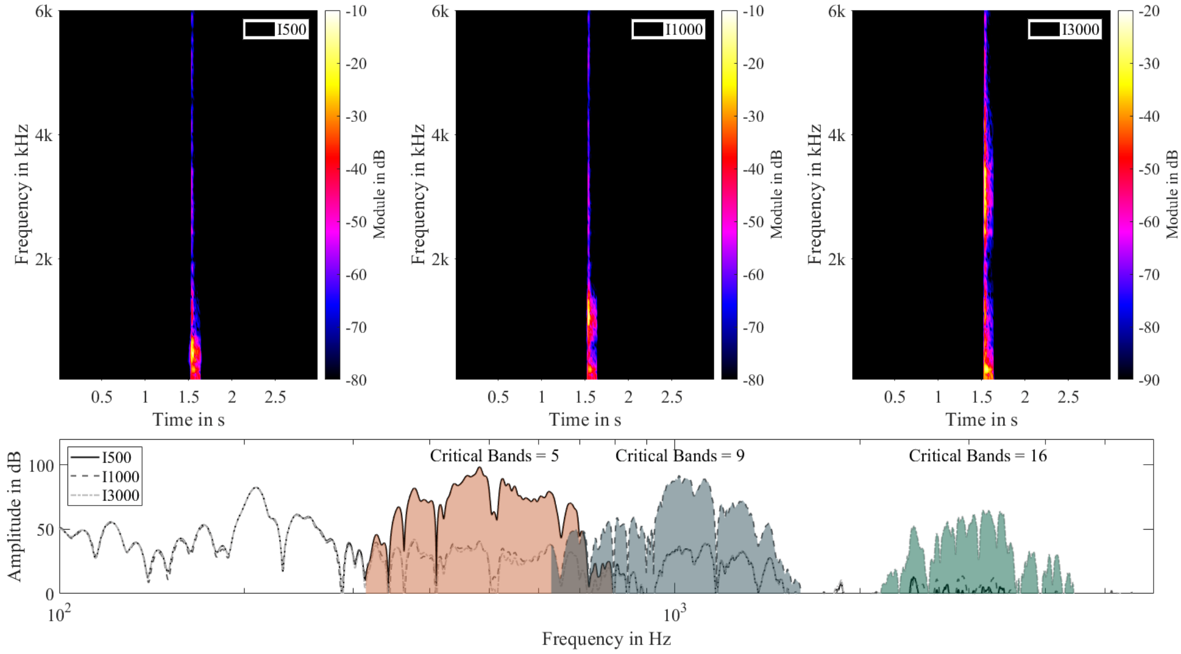

Figure 3 – Reference signals filtered with bandpass filters tuned to the central frequencies of 500 Hz, 1000 Hz and 3000 Hz.

The refrigerator in a permanent state was recorded and the acquired signal was used as a masking signal in the subjective test. Combination between each reference signal and compressor noise represented a session in the remote test.

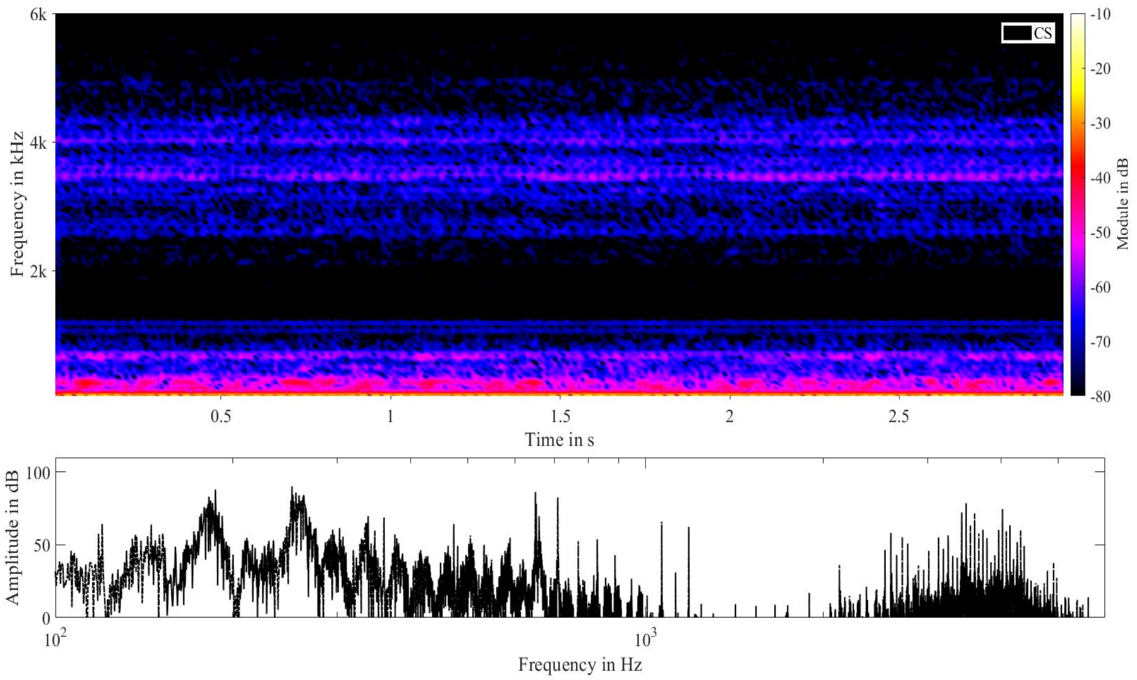

Figure 4 – Masking signal from the recording of a permanent refrigerator.

Like the reference signal, the masking signal was recorded for 3 seconds in a semi-anechoic chamber. However, for this case, no processing was done on the signal. The masking signal is seen in Figure 4.

2.2 Remote Test

One of the great challenges of this work was to accurately obtain the differential threshold of impulsive signals for different frequencies. Remotely and asynchronously, the researcher has no control over the test, and there is not possible to know if the user has understood the test instructions. The advantages offered by an online platform are the practicality in applying the test and the sample space, which tends to be larger than a face-to-face test. The remote trial was proposed as a way to perform a psychophysical test during the COVID-19 pandemic. The test was conducted asynchronously.

2.2.1 Development of an Online Platform

To create a virtual environment a digital web browser platform was used. The structuring of the page was done using *Html* and *Css* as programming languages, while *JavaScript* was used for the front end, being incorporated in the steps of convergence of responses, and processing of impulsive signals. To send data to the server the language adopted was *Php*.

First, a registration area was developed, where it was possible to obtain some user data, such as name, age, gender, and whether respondents have some knowledge in acoustics. In this way, it was possible to stratify the sample. After the registration area, the user was forwarded to a "welcome" page, where some instructions were passed. The instructions were divided into two groups: instructions for performing the test, and instructions for the test interface. To perform the test, the instructions guided the user to go to a quiet environment, use headphones and avoid interrupting the test once it started. The interface instructions gave guidelines on how the interface worked, informing about the sounds and functionality of each button. Finally, the user was guided to the test area, where the reference sound signals and the mask signal were presented.

2.2.2 Design of Subjective Evaluation Experiment

For each user, the order of presentation of the reference signals was random, and the reproduction occurred simultaneously with the masking signal. The amplitude of the reference signal was randomly assigned at the beginning of the test and changed depending on the user's response to the question "Did you hear the reference signal?". For positive responses, the amplitude of the reference signal was divided in half, on the other hand, for negative responses, the amplitude of the reference signal was doubled. For both responses chosen by the subjects, the amplitude of the masking signal remained constant. The convergence criterion adopted was associated with the amplitude history of each session, so that the test ends, the mean between the amplitude values must be smaller than the difference between the two last obtained values [9]. The interface used in the test and the flowchart applied to determine the differential threshold are shown in Figure 5. The average time for users to end each session was approximately 5 minutes, totaling 15 minutes of testing for all sessions (500 Hz, 1000 Hz and 3000 Hz).

2.3 Participants

The sample consisted of men and women aged between 13 and 64 years, totaling 247 people. From the total sample 83 (33.6%) outliers were removed from the sample from the detection of elements with values that is more than three scaled median absolute deviations (MAD) [10]. The subjects' mean age was 34.2 years. The sample was divided between laypersons and experts by a dichotomous question "Do you have knowledge in Acoustics?" 57 (30%) of the participants scored positively for knowledge and acoustics. Unfortunately, it was not possible to perform audiometric tests on the sample because the test is exclusively remote. Those data would be very relevant for assessing the hearing health of the sample members. Furthermore, it could be used to help detect outliers.

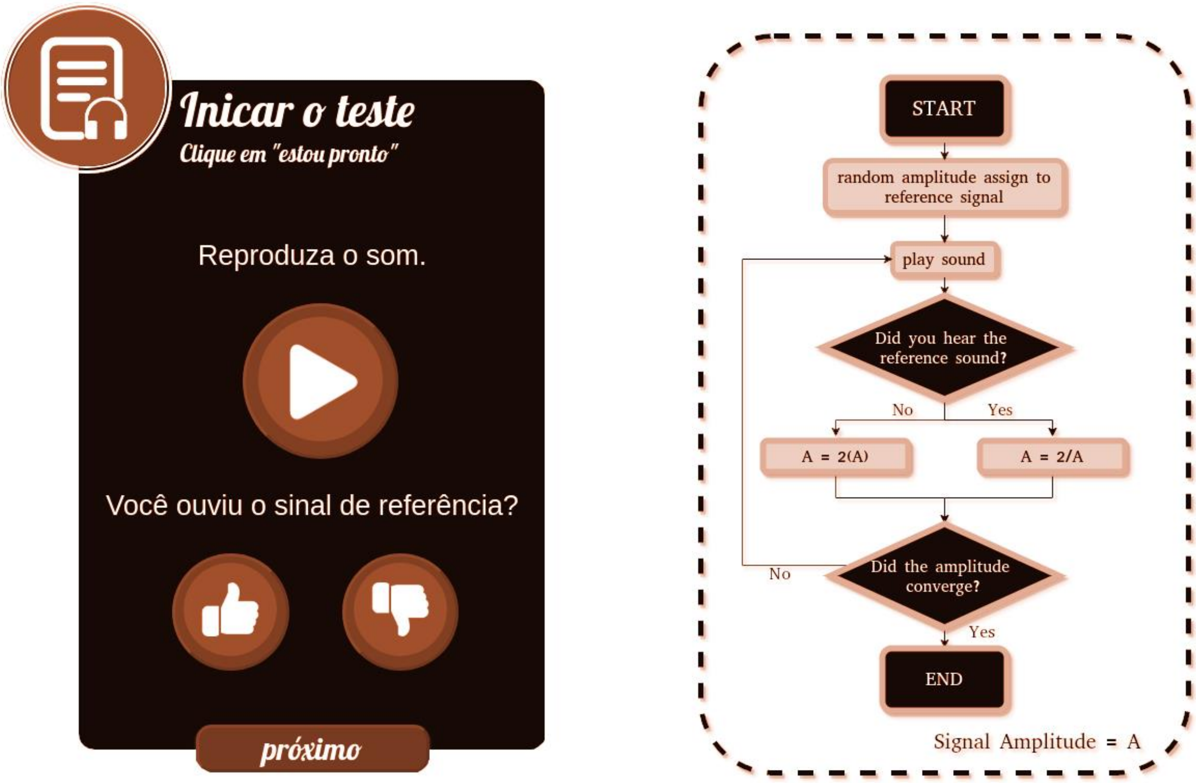

Figure 5 – The interface used in the test and the flowchart applied to determine the threshold.

3 Results

The tests results were used to obtain the impulse signals hearing thresholds for different frequency ranges. The data refer to tests carried out between March and May 2021. Values were analyzed globally (see Figure 6) and stratified, considering the division of the sample by gender, age and knowledge in acoustics (see Table 1). The results show that both globally and stratified, the values obtained for the thresholds depend on the central frequency of the filter. Impulsive signals with energy concentrated at low frequencies showed higher hearing thresholds, while impulsive signals with energy concentrated at higher frequencies showed lower hearing thresholds. Furthermore, the confidence intervals for impulsive signals filtered with lower frequencies were higher compared to those filtered with high frequencies, that is, there was more dispersion of data with tests with impulsive signals of low frequencies.

Data dispersion was analyzed in each trial number in all sessions (see Figure 7). As well as the results of global threshold values, the confidence interval was greater for signals with energy concentrated in low frequencies compared to signals with energy in high frequencies. The signal with the central band of the filter tuned at 1000 Hz reached the lowest number trial, indicating that the test converged faster than the other sessions.

The general sample, counting only valid subjects (excluding outiliers), was composed of 190 people, being 136 (71.58%) men and 54 (28.42%) women. As for age, 95 (50.0%) of the individuals were in the range of 20 - 30 years, while the range of 60 – 70 years had only 3 (1.58%) individuals. In addition, 57

(30.00%) people were counted as specialists, against 133 (70.00%) who were dominated by inexpedient people.

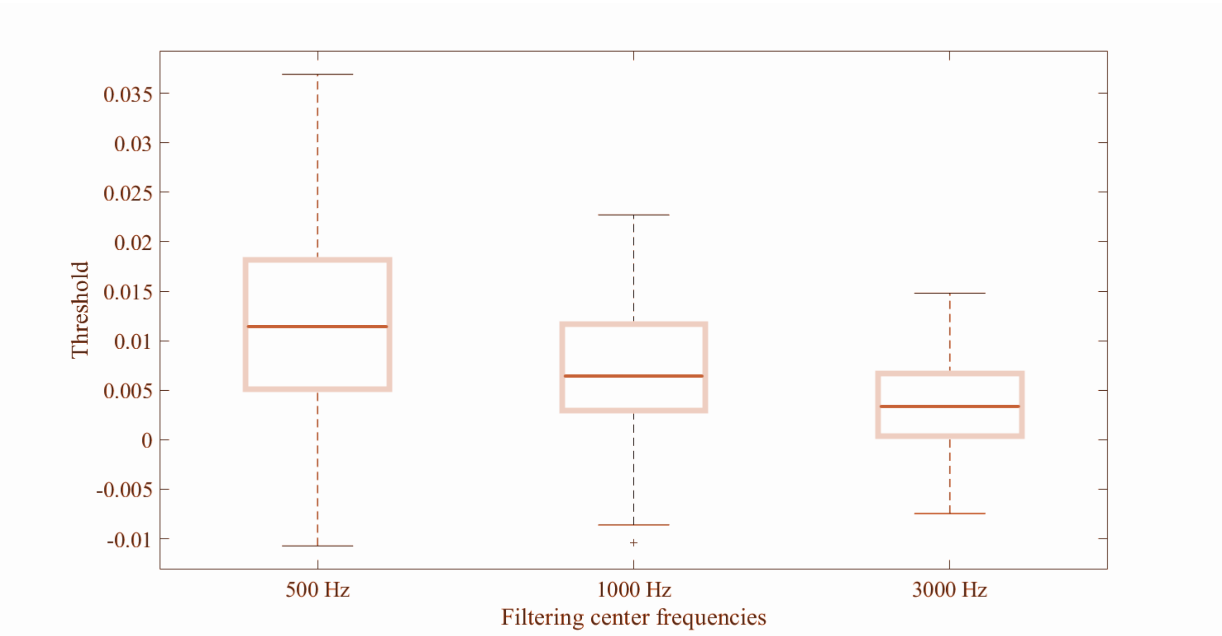

Figure 6 – Global thresholds obtained for the signals filtered with bandpass filters tuned to the central frequencies of 500 Hz, 1000 Hz and 3000 Hz.

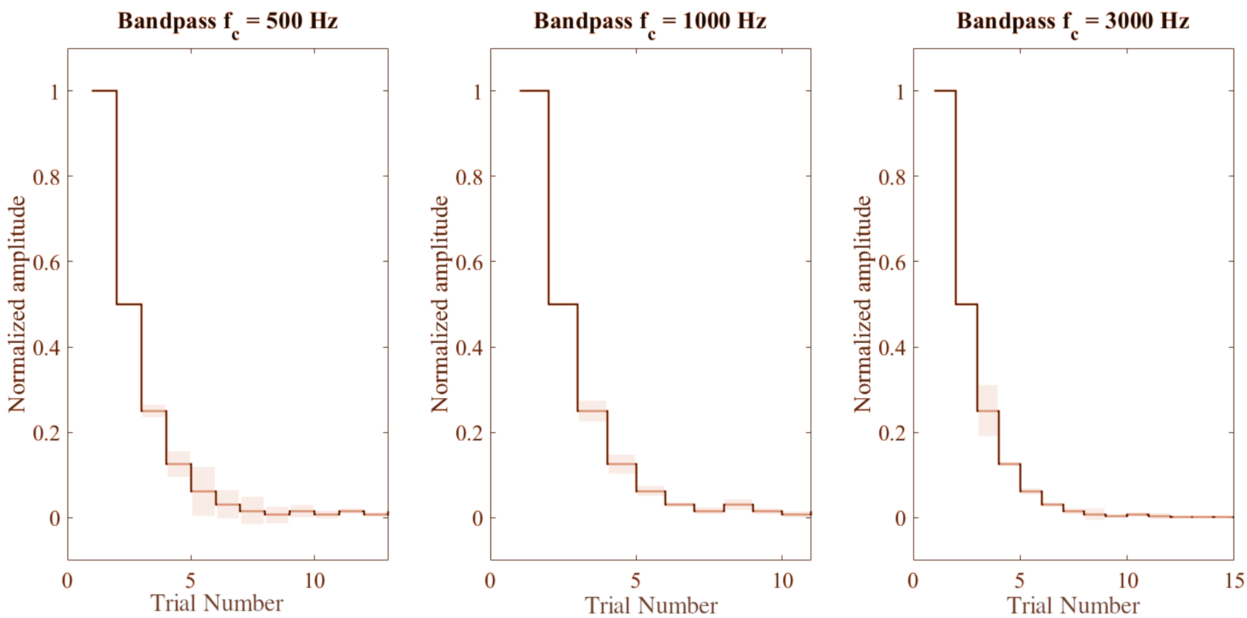

Figure 7 – Data dispersion in each session trial number

Among the stratified results (seen in Table 1), the threshold values obtained according to gender stand out, where it was observed that, in general, women had lower thresholds compared to men, except for the central band of 3000 Hz, which values were pretty much the same. Analyzing the data by age, it was found that ranges between 50-60 years and 60-70 years reached higher thresholds than other age groups. As for knowledge in acoustics, specialists obtained better results with lower thresholds compared to results obtained by laypersons.

4 Conclusions

The characterization of impulsive signals is a task that involves knowing the frequency ranges that the signals cause the greatest sensitivities for people. Furthermore, specifically for refrigerators, this classification can be of great help in the manufacture of products that cause less discomfort for the consumer.

The results obtained showed that, in general, the impulsive signals with energy at low frequencies had the lowest thresholds compared to the signals with energy at higher frequencies. Women had lower thresholds compared to men, as well as specialists, who had better results compared to laymen. In addition, older people had higher thresholds.

The digital platform showed good results in subjective tests. Greater data dispersion was expected, as it was not possible to follow most tests. This shows that the instructions passed at the beginning of the test were effective. The applied methodology is practical and managed to achieve a relatively large sample space, given the time that the data were computed, which indicates be an effective tool for applications in sound quality. Moreover, in more favorable situations the execution of in-person tests, it is expected to compare the results obtained remotely and in-person form.

Acknowledgements

This work was carried out with the support of the Brazilian National Council for Scientific and Technological Development (CNPq) of Brazil.

Table 1 – Stratified thresholds

Sociodemographic variables	**Sample size (%)**	**Threshold (Mean ± CI 95) Filtering center frequency**		
		500 Hz	1000 Hz	3000 Hz
Gender				
Male	136 (71.58)	0.012350 ± 0.001613	0.007180 ± 0.001131	0.0035 ± 0.000758
Female	54 (28.42)	0.009124 ± 0.003025	0.008009 ± 0.01832	0.003738 ± 001873
Age				
10 - 20	15 (7.90)	0.011065 ± 0.004509	0.006555 ± 0.003006	0.005597 ± 0.002010
20 - 30	95 (50.00)	0.012507 ± 0.001901	0.006689 ± 0.001344	0.003249 ± 0.000935
30 - 40	43 (22.63)	0.009668 ± 0.002702	0.007837 ± 0.001632	0.003769 ± 0.001655
40 - 50	16 (8.42)	0.012805 ± 0.005043	0.006526 ± 0.003920	0.003759 ± 0.001559
50 - 60	8 (4.21)	0.012863 ± 0.004469	0.006641 ± 0.004241	0.004014 ± 0.003012
60 - 70	3 (1.58)	0.014217 ± 0.012521	0.010364 ± 0.009653	0.009361 ± 0.00430
Knowledge in acoustics				
Layperson	133 (70.00)	0.012018 ± 0.002381	0.007320 ± 0.001696	0.002406 ±0.001175
Experts	57 (30.00)	0.010874 ± 0.001619	0.007149 ± 0.001156	0.003472 ± 0.00756
Total	190 (100.00)	0.011564 ± 0.001349	0.007287 ± 0.00093	0.00356 ± 0.00067

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