Euronoise 2018 Crete

Frequency Spectra Discrimination of Broadband Stimuli

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Summary
The sensitivity of human hearing is one of the important aspects determining daily living and acoustic comfort. In this paper, the ability of people to discriminate between frequency spectra obtained by filtering out different frequency bands from the spectrum of broadband noise stimuli was tested. Subjective laboratory listening tests were designed and optimized, using the three-alternative forced choice method. The width of the frequency gaps was varied in between 1, 2, 4, 8, 12 and 16 semitones, and reductions 0.3, 0.5, 1, 2, 3, 5, 10 and 20dB were applied. The gaps were created symmetrically (on a logarithmic scale) around two central frequencies: 125Hz and 2000Hz. Altogether 39 subjects were tested.

PACS no. 43.55.+p, 43.66.+y

1. Introduction

The sensitivity of human hearing has always been a research topic that has attracted interest of many research groups [1, 2, 3, 4].
Recently, a revision of international standards related to sound insulation and single number quantities [5] has opened new questions in which the human hearing sensitivity spectrum plays an important role [6, 7, 8, 9].
In particular, as resonance and coincidence effects of partitions cause dips in their sound insulation frequency spectrum, the question is what the audibility thresholds of the dips are, in terms of their shape (width and depth).

This paper presents a preliminary study that shows to what extent are people able to recognize the gap in the frequency spectra of broadband stimuli – in our case pink noise of 80 dB(A).

2. Description of experiments

2.1. Listening subjects

Thirty-nine listening subjects participated in this preliminary study. All of them were in the age between 21-53 years old, with normal hearing.

2.2. Stimuli

The stimuli were chosen as follows: First, as a reference signal, a pink noise of total sound level 80 dB(A) and duration of 0.3 seconds was chosen. Second, a set of stimuli was created by applying a notch filter of different width and depth. The central frequency of the notch filters was either low (a. 125 Hz) or high (b. 2000 Hz). For the dips with central frequency of 125 Hz, combinations of 5 different widths (2, 4, 8, 12, 16 semitones) and 7 depths (20, 10, 5, 3, 2, 1, 0.5 dB) were created. Since the human hearing is more sensitive for high frequencies in comparison with low frequencies, we considered smaller widths (1, 2, 4, 8, 12) and more shallow depths (10, 5, 3, 2, 1, 0.5, 0.3) for the dips with central frequency of 2000 Hz. The length of each stimulus was 300 ms.

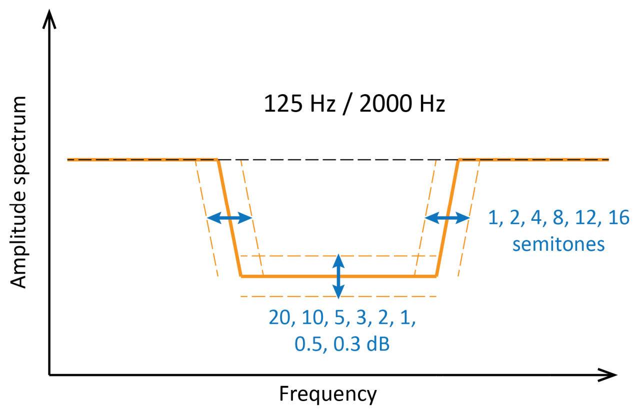


Fig. 1 Various combinations of width and depth of the notch filter used to prepare stimuli

The way of filtering of stimuli as well as all variants are shown in the Fig.1. The total amount of different combinations led to creation of 70 stimuli.

2.3. Listening test protocol and presentation of stimuli

The listening tests were interactive. Each participant was operating a graphical user interface (GUI) and could freely decide when the sounds should be played. The test subjects were asked to choose their answers from a menu on the computer screen, by use of a mouse click. The three-alternative forced choice method was used in all listening tests. The listening test routine was programmed in VBA software. A printscreen of the GUI is shown in Fig. 2.

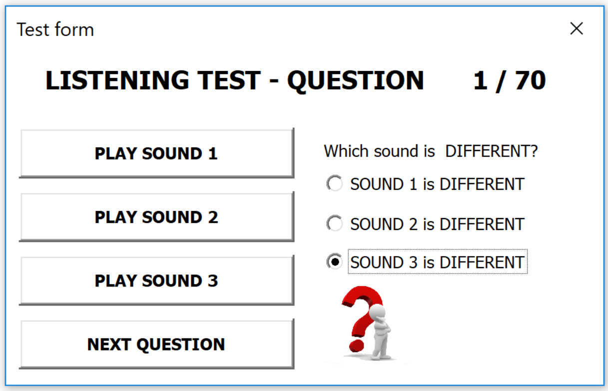
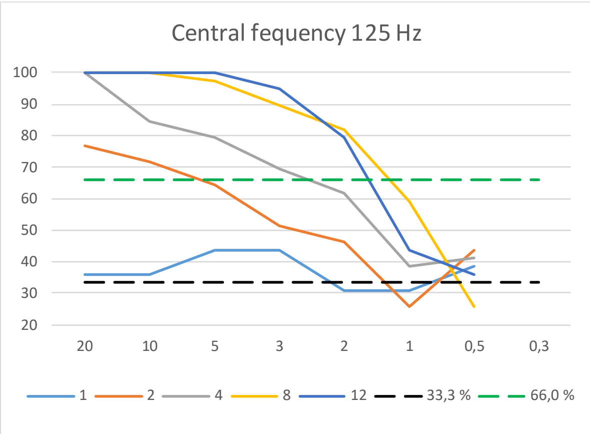


Fig. 2 GUI of listening test

The stimuli were always presented in triplets. Test subjects could subsequently play sound 1, sound 2 and sound 3 as many times as needed and were asked to decide which of the 3 sounds was different from the two others. In these triplets, two of the sounds were always set to be the reference stimulus, i.e. pink noise with level of 80 dB(A). The remaining sound was one of the 70 above mentioned stimuli. The sounds in each of the 70 presented triplets were organized in random order. The test subjects could play next sound only after the previous one was finished. Prior to the test, they received some instructions on how to use the GUI but in order to avoid biased results, they were not informed about the purpose of the experiment.

The average duration of the tests was about 35 minutes, with individual variations depending on the rate of answering. The answers were automatically saved as the subjects were proceeding and were analyzed later.

All listening tests were performed in a silent listening room at Faculty of Electrical Engineering and Electronics, University of Zagreb. The listening test setup consisted of a computer, which was connected with an external sound card. The stimuli were played through open headphones with a flat frequency response.



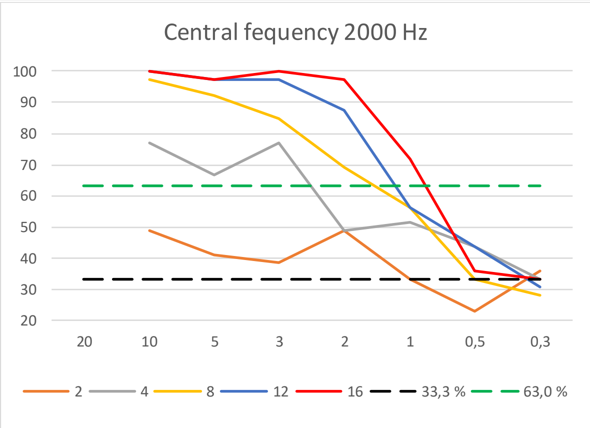


Fig. 3 Percentage of correct answers for various combinations of width and depth of the notch filter that was applied on 80dB(A) pink noise. The horizontal axis denotes the applied dip depth in dB. The different colors denote the dip width in semitones. The black dashed line indicates the guessing limit of 33,3%. The green dashed line shows the percentage of correct answers averaged over dip depths between 10 dB and 0.5 dB and dip widths between 2 semitones and 12 semitones.

3. Results and discussion

Figure 3 depicts the percentages of correct answers on the question which of three presented sounds was different from the other two, for each dip width (different colors) and depth (horizontal axis), and for both central frequencies (top: 125Hz, bottom: 2000Hz). The percentages of correct answers for the same widths, averaged over dip depths between 10 dB and 0.5 dB were 66% and 63% for central notch filter frequencies of 250 Hz and 2000 Hz respectively. Since for both central frequencies almost all of the answers for a dip width of 1 semitone (light blue line) were correctly answered only about 33.3% of the time, the guessing limit, it can be concluded that a dip of 1 semitone is not audible.

In contrast, dips with a width of 10, 5 and 3 semitones was relatively easy to detect, for depths 8 dB and more. Compared to 125Hz, subjects performed slightly better for stimuli with central frequency of 2000 Hz in almost every combination of the gap width and depth. This is consistent with the human hearing being more sensitive at 2000Hz [10]. For dips around 2000Hz start to be detected for 1dB depth or more. Dips around 125Hz are only audible when their depth exceeds 2dB.

4. Future work

Our future work will be focused on investigation of the mentioned features in frequency spectra at lower sound pressure levels.

Besides the intrinsic added value of quantifying the audibility of spectral dips, the presented work can be considered as a first step towards the different but analogous question whether narrowband spectral details (e.g. corresponding to insulation dips due to coincidence, structural resonance or application of an external thermal insulation system) of sounds heard through different building elements (typically varying between 1/3 and ½ octave width and between 0dB and 20dB depth) are audible. This question is important with respect to making sustainable and effective use of resources when putting effort in innovations that are intended to improve in an audible way the sound insulation of building elements.

Acknowledgment

This research has been made within the scope of the H2020-MSCA-RISE-2015 “PaPaBuild„ project (grant agreement No. 690970). This research was supported by national project VEGA 1/0050/18.

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