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Audibility of spectral dips and peaks in broadband noise

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Abstract

The paper reports on the ability of people to discriminate between broadband pink noise-based sounds that differ concerning the presence or absence of a peak or dip in their spectrum. Stimuli were created by damping or amplifying a frequency band centered around 125Hz or 2kHz of broadband pink noise with varying bandwidth and reduction/enhancement factor. Perception tests involving 12 human subjects show that spectral dips are more difficult to detect than peaks. Those tests also present significantly lower audibility performance for spectral changes located in the low frequency range. For subtle contrast levels, the audibility of the filtrated pink noise lightly increases with the sound pressure level of the presented stimulus.

Keywords: Psychoacoustics, Frequency audibility, Building acoustics

1. Introduction

The main motivation for this experiment lies in two running project that relate to (1) subjective assessment of sound insulation (EU H2020 MC RISE "Papabuild" project [1]) and (2) dissertation project on Echolocation. In both project the same questions arise related to audibility of spectral dips and peaks in broadband noise. Detecting subtle spectral differences between sounds is relevant in architectural acoustics, for people with a visual handicap who are navigating in a space by means of echolocation and acoustic recognition. Assessment of spectral differences is also relevant in a room and building acoustics context, respectively in the framework of interpreting just noticeable differences in colour of sound reflection from interior surfaces; and in the judgment of sound transmission spectra that differ due to subtle sound insulation deteriorations or improvements of walls. The following experiment was performed as a pilot study prior to next more detailed research in this topic.

2. Listening test experiment

2.1 Participants

A group of 12 sighted people, composed by 7 males and 5 females, between 18 and 55 years old, participated at the listening test experiments. They had been informed in advance about the purpose of the experiment, however without knowing the specifics of the presented stimuli. Most of the subjects performed a listening test for a first time and none of them was an expert in acoustics. The participants were volunteers and no financial of other compensation was given to them. The subjects' hearing was tested from 250 Hz to 8 kHz using a screening audiometer AS7 (Kampler®). Only participants having a hearing threshold smaller than 20 dB (Hearing Level) were asked to participate in the psychoacoustic 2 Alternative Forced-Choice (2AFC) test. Every participant had given informal consent to perform this experiment and use its material for research purposes. This research has been approved by the Social and Societal Ethics Committee of KU Leuven (SMEC) [2].

2.2 Apparatus

The listening tests were carried out in a 125 m^3 semi-anechoic chamber and presented to one person at a time, after being instructed about the task procedure, and without prior training. The listening tests were conducted making use of a Scarlett 6i6 (Focusrite®) soundcard broadcasting sound samples via SPDIF to a listening unit HPS IV (Head Acoustics®). High-quality open headphones HA II.1 (HeadAcoustics®) were used to present the audio stimuli. The sound devices were set with a sampling frequency of 48 kHz and a bit resolution of 16 bits.

2.3 Stimuli

The stimuli were based on pink noise reference signal of 1 second duration, sinusoidally faded during 200 ms. Different variations were synthesized by increasing or decreasing the level of the spectrum with different amounts across a rectangular window with different widths. Two central frequencies were studied, 125 Hz and 2 kHz. In the following, these are referred to as 'low' and 'high' central frequencies respectively. For each of these, 5 bandwidths were compared, from 2 to 16 semitones for the low central frequency, and from 1 to 12 semitones for the high central frequency, as presented in **Figure 1**. The modified bandwidth range was chosen more narrow for the high central frequency in view of expectations that peoples hearing sensitivity is larger around 2kHz than around 125Hz. The level changes were -1, -3, -6, -12 dB (A-weighed) for spectral dips and +1, +2, +3, +6 dB (A-weighed) for spectral peaks.

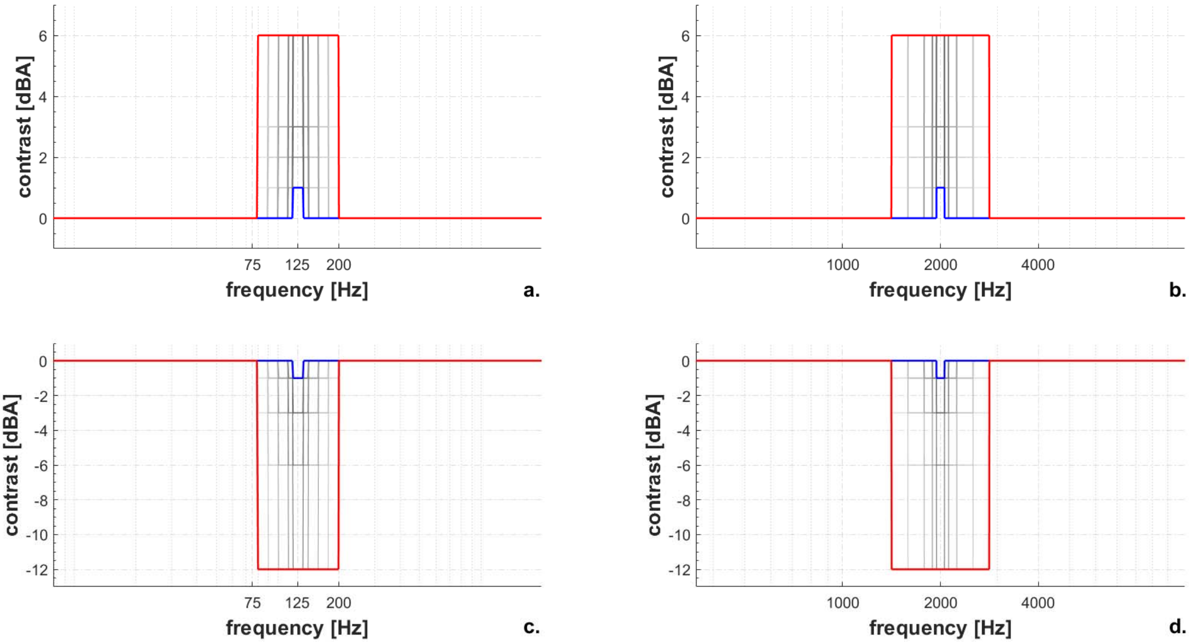

Figure 1. Applied filter functions containing rectangular peaks (a, b) and dips (c, d), centered around 125 Hz (a, c) and 2 kHz (b, d). The widest filters with the largest contrast are represented in red. The narrowest filters with the smallest contrast are displayed in blue. The others are depicted in different shades of grey.

The stimuli were presented at two sound pressure levels, respectively 35 dB (A-weighed) and 50 dB (A-weighed), being calibrated with a head and torso simulator HMS III (HeadAcoustics®). We refer to these levels as 'low' and 'medium' respectively. A total of 80 different stimuli were generated, corresponding to 2 presentation levels, 2 central frequencies, 4 filter contrast, 5 bandwidths; and presented twice in random order.

2.4 Task and procedure

The listening test was of ABX-type, i.e. a psychoacoustic method 2AFC [3] experiment presenting 3 signals respectively named A, B and X, with A and B being 2 different signals and X randomly equal to one of the others. A and B were set either to the reference signal or to one of the filtered pink noise signals. The listener was asked to answer whether X was equal to stimulus A or stimulus B. This type of psychoacoustic test has a guessing limit of 50 %. The more the correct answering performance is above 50%, the higher is the detectability of the tested filter feature. The listening test was presented using a custom graphical user interface in Matlab® displayed on a computer screen. The participant could select his or her answer using a keyboard or using a low noise producing mouse (M220 Logitech®). The keyboard shortcuts were pre-programmed and not modifiable by the user during the test. No instructions were given to the participants regarding the order and the number of stimuli. However, they were advised to not spend more than 2 minutes on a single comparison. The experiment was split into 4 tests: dips and peaks were presented in separate tests, with a further division for the presentation level: 35 dB (A-weighed) and 50 dB (A-weighed). The order of presentation of those tests was randomly assigned by the listening test software. The impressions of the participants were asked after every test in order to fix a small resting time between every test and thus help people to perform without fatigue. A 10 minutes break was offered to the participants in the middle of their session for the same purpose. The average duration of the sessions was about 1 hour and 25 minutes, though this strongly varied between participants.

3. RESULTS AND DISCUSSION

Analysis of results was performed using statistical method ANOVA - repeated measures, with the goal of assessing the degree of audibility of spectral dips and peaks with different filter contrast levels and widths, for the two central frequencies 125 Hz and 2 kHz, and for different presentation levels, 35 dB (A-weighed) and 50 dB (A-weighed).

Figure 2 and 4 (peaks) and **Figures 3 and 5** (dips) show that people's performance to detect dips and peaks is significantly better when those are centered around 2 kHz than around 125 Hz ($p = 0$), with detection thresholds less than or of the order of 1 and 3 dB contrast respectively. This can be explained by the better hearing sensitivity of people around 2 kHz and infers that when room acoustic adaptations are made in an architectural context with the aim of adding acoustically salient features in order for blind people to recognize specific objects by echo-recognition, best is to focus on spectral modifications at not too low frequencies [4]. The lower audibility of spectral details around 125 Hz also suggests that efforts to improve the acoustic insulation of walls are more effective when aimed at the higher part of the spectrum [5, 6]. Equivalent results were made on recent research on human echolocation, claiming better obstacle detection in the high frequency range, from 3.5 to 4.5 kHz [7], entailing a better sensitivity of their users to high frequency content.

Comparing the audibility of dips and peaks for the same absolute value of the filter contrast, the peaks are found to be more easily identifiable than the dips ($p = 0$). This finding implies that in the framework of adding acoustic markers to items in spaces with the goal of letting them being detected by echo-recognition, best is to implement objects with a peak in their reflection spectrum rather than a dip.

For the smallest contrast levels, the performance is slightly better for sounds presented at 50 dB (A-weighed) compared to 35 dB (A-weighed) ($p = 0.039$). The average score for the lower contrast levels tends to improve with increasing width of the dips and peaks. However, interestingly, this trend is not always monotonic: for a central frequency of 125Hz and for several contrast levels, the most narrow peaks and dips are detected more often than the wider ones.

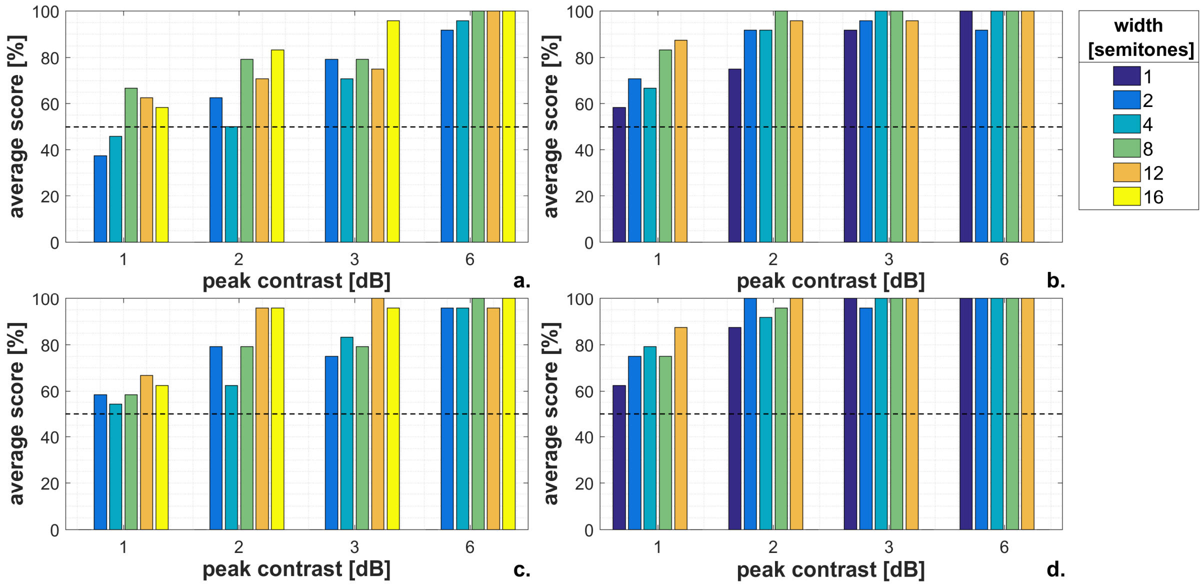

Figure 2. Audibility of filtered pink noise as a function of the width and contrast of a spectral peak for 2 sound pressure levels of 35 dBA (a, b) and 50 dBA (c, d) and 2 central frequencies: 125 Hz (a, c) and 2 kHz (b, d) tested on 12 sighted people. The level of accuracy corresponding to the 50% guessing limit is represented by the dashed line.

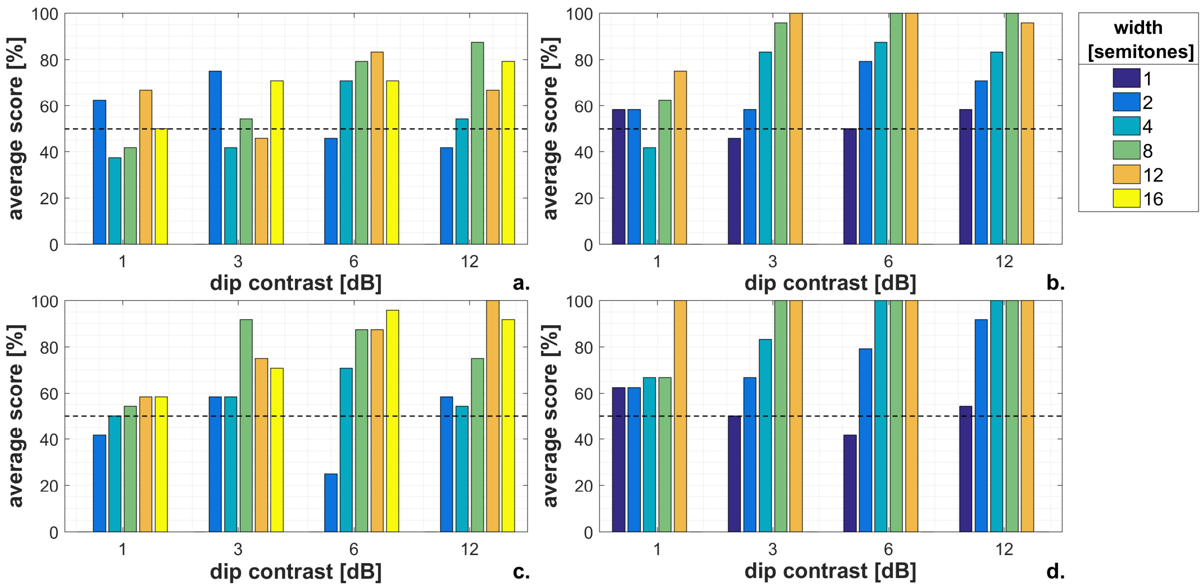

Figure 3. Audibility of filtered pink noise as a function of the width and contrast of a spectral dip for 2 sound pressure levels: 35 dBA (a, b) and 50 dBA (c, d) and 2 central frequencies: 125 Hz (a, c) and 2 kHz (b, d) tested on 12 sighted people. The level of accuracy corresponding to the guessing limit (50%) is represented with a dashed line.

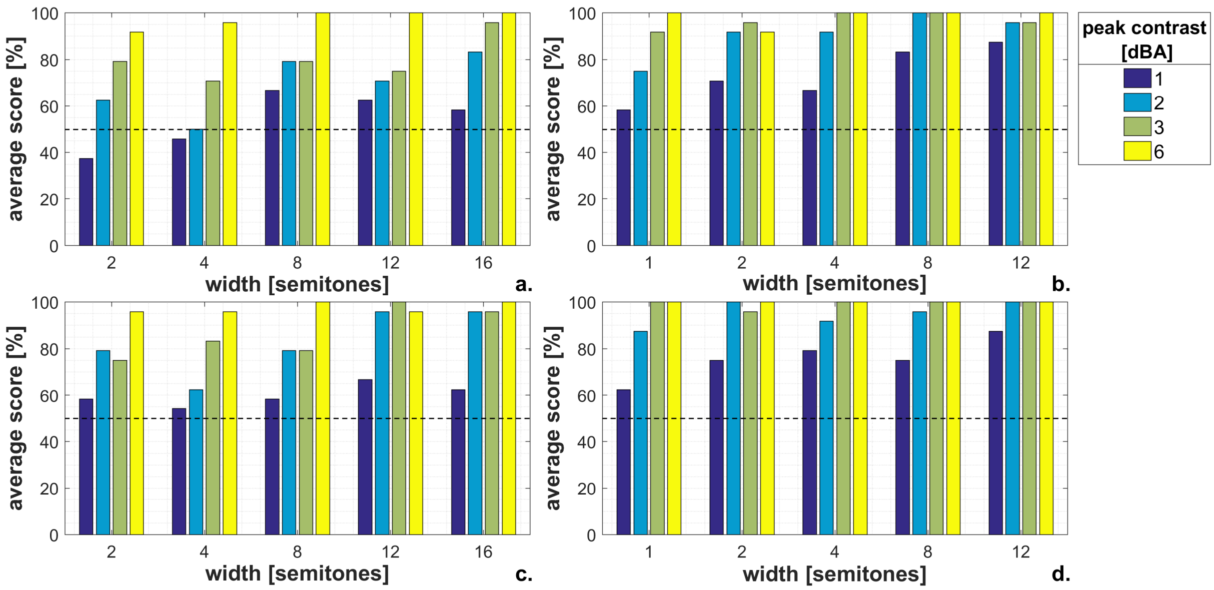

Figure 4. Audibility of filtered pink noise as a function of the contrast and width of a spectral peak for 2 sound pressure levels of 35 dBA (a, b) and 50 dBA (c, d) and 2 central frequencies: 125 Hz (a, c) and 2 kHz (b, d) tested on 12 sighted people. The level of accuracy corresponding to the 50% guessing limit is represented by the dashed line.

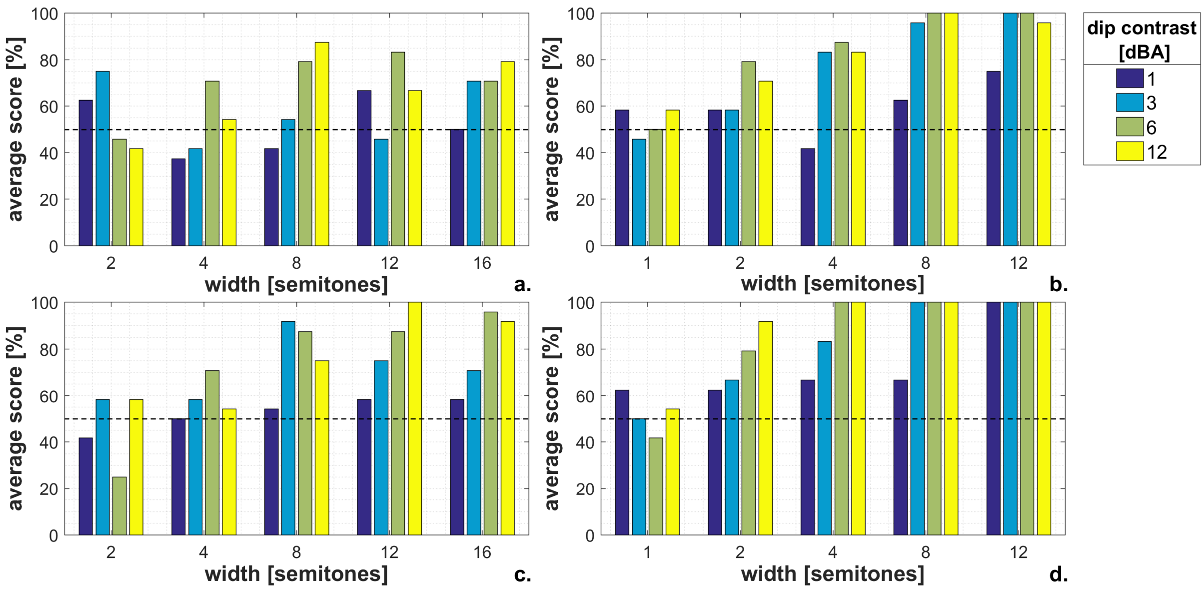

Figure 5. Audibility of filtered pink noise as a function of the contrast and width of a spectral dip for 2 sound pressure levels: 35 dBA (a, b) and 50 dBA (c, d) and 2 central frequencies: 125 Hz (a, c) and 2 kHz (b, d) tested on 12 sighted people. The level of accuracy corresponding to the guessing limit (50%) is represented with a dashed line.

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