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WHAT KIND OF SPECTRUM ANNOYS US THE LEAST? A PSYCHOACOUSTIC EXPERIMENT EXPLORING STEADY STATE NOISES

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ABSTRACT

It is common for certain penalties to be applied for tonal and impulsive noise. However, the spectrum is the most usual descriptor of sound after the overall level. There is relatively little scientific and psychoacoustic evidence on the influence of spectral shape and level on the subjective annoyance of steady-state noises. Here, we present a pilot psychoacoustic experiment in which ten listeners rated the annoyance of 23 steady-state noises with different spectral shapes reproduced at three different sound pressure levels (32, 40, and 48 dB LAeq). The test also included reference noise sounds in a range of 28 to 60 dB LAeq that enabled the estimation of the spectrum-dependent "penalty" caused by the subjective annoyance at a specific level. The results indicate that steady-state noises containing more high frequencies than low frequencies are perceived as more annoying than sounds that contain more low frequencies. While the presentation level increased the perceived annoyance, it did not seem to influence the penalty values. The study shows that a penalty should also be given for broadband steady-state sounds having a specific spectrum. The results can also be used in the development of comfortable masking sounds.

Keywords: *noise, spectrum, annoyance, penalty*

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1. INTRODUCTION

Environmental noise regulations are generally based on the sound level expressed in A-weighted equivalent sound pressure level, L_{Aeq}. Sound level may be the main determinant of the perceived annoyance of noise, but it is not an exhaustive one because people are disturbed by several sound qualities which are not directly reflected in L_{Aeq} values. Spectral shape [1], tonality [2] impulsiveness [3], and amplitude modulation [4] also need to be considered in assessing the perceived annoyance of noise. If the sound fulfills specified criteria on one or more of these aspects, the L_{Aeq} value is adjusted to better represent the perceptual consequences of the noise. In practice this means adding a penalty (a.k.a. adjustment, sanction, surplus, bonus) to L_{Aeq} and the adjusted level, $L_{Aeq} + k$ is then used in checking with the regulations.

The penalty depends on the sound quality under inspection and how much noise deviates from a neutral / reference condition. For instance, Oliva et al. [2] found that the penalty of tonal sounds was greater when the frequency and audibility of the tonal component were increased and could be as large as 12 dB. For impulsive sounds, Rajala and Hongisto [3] found that penalty increased with the onset rate and level difference of the impulsive components and could be as much as 8 dB. In a similar fashion, Virjonen et al. [4] found that the penalty of amplitude modulated sounds increased with increasing modulation frequency and depth and could be as much as 12 dB.

Considering that spectrum is a critical factor in terms of subjective annoyance, it is surprising how controversial the psychoacoustic evidence is in this respect. For instance, Persson and Björkman [5], and Schäffer et al., [6] have reported low frequency noises to be more annoying than other noises, while Landström et al., [7] and Hongisto et al. [1] reported the opposite, that the high frequency sounds are more annoying. This controversy may be due to different experimental designs and research contexts, but there is clearly a need for collecting more psychoacoustic evidence on how spectral shape influences noise annoyance.

The current experiment can be considered an extension of the previous study [1] where annoyance ratings were collected for 11 spectrally different steady-state noises, but which lacked the penalty analysis and only presented sounds at a constant level of 42 dB L_{Aeq}. The current study extents this work by including the penalty analysis and a wider range of different spectra. We also presented sounds at three different sound levels to study the possible influence of L_{Aeq} level on annoyance ratings and penalty values and to better meet different sound levels present in residential dwellings (usually under 32 dB), offices (usually under 40 dB), and public spaces (usually under 48 dB).

2. MATERIALS AND METHODS

2.1 Participants

Ten people between 19- and 35-years old participated to the psychoacoustic laboratory experiment. All participants had normal hearing verified with a pure tone audiometry.

2.2 Design of experiment

The penalty for a sound is derived by projecting the annoyance rating of the sound onto a reference line. Thus, the design of the experiment included establishing the reference line with a set of reference sounds as well as collecting annoyance ratings of experimental sounds. The reference sounds were presented at 28, 32, 36, 40, 44, 48, 52, 56 and 60 dB L_{Aeq} levels. The experimental sounds were presented at 32, 40 and 48 dB L_{Aeq}.

The experiment started with familiarization and training phases, which introduced the listeners to the range of different spectra and sound levels included in the experiment and allowed them to practice using the GUI. After training, the participants gave annoyance ratings for all 78 stimuli. The presentation order of all sounds (experimental and references) was fully randomized between participants.

Listeners rated the annoyance on an 11-point discrete scale ranging from 0 to 10 and labelled “Not at all” (annoying) and “Extremely” (annoying), respectively. There was also an option “I did not hear any sound” if the sound was not perceived.

2.3 Setup

The experiment took place in an acoustically treated listening room with background noise level under 20 dB L_{Aeq}. The average reverberation time (T20) over 125 to 8000 Hz octave bands was 0.2 seconds. Sounds were played back from two loudspeakers hidden above the suspended ceiling.

2.4 Stimuli

Previous research [1] indicated that the least annoying spectrum had a slope of -5 ... -7 dB per octave. Thus, to ensure that the reference spectrum would be among the least annoying, we selected a slope of -9 dB per octave as the reference sound spectrum.

The experimental sounds included different kinds of spectral shapes, see Fig 1. There were noises with different spectral slopes (Fig. 1a), some of which are also known by their color-names (e.g., white, pink, brown etc.). There were octave band noises (Fig. 1b) as well as lowpass-, high pass-, and bandpass- noises (LP1000, HP1000, BP1000, Fig 1b). RC40 and NC40 noises exhibit spectral shapes of the curves that are used in the objective assessment of noise in buildings. We also included three speech shaped noises SIIsp, SMS1, and SMS2. SIIsp was based on the speech spectrum provided in the ANSI S3.5-1997 standard. SMS1 and SMS2 were based on a commercially available masking noise system, with the difference that SMS2 was extended to lower frequencies in comparison to SMS1. We also included equal-loudness contour -shaped noises (phon32/40/48) and inverse A-weighted spectrum shaped noise, which is also sometimes referred to as “grey” – noise.

Different spectral shapes were achieved by playing back and filtering white noise with a third octave band parametric equalizer. The sound was captured at the listening position with a monophonic microphone. The equalizer gains were adjusted until there were less than a three-decibel level difference in each third octave frequency band between the measured and the target spectra. The creation of the sounds was done in MATLAB. The playback levels of all sounds were set to the desired A-weighted SPLs by using sound level meter. All A-weighted sound pressure level values were within +/- one dB of their target levels. The generated sounds were 20 seconds long.

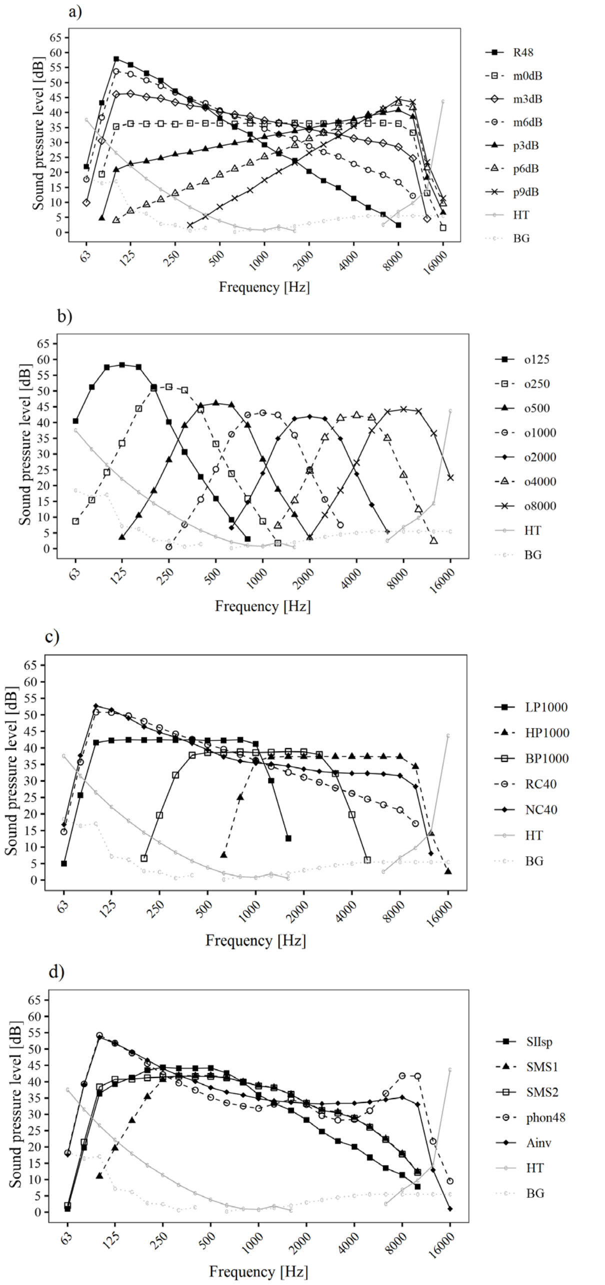

Figure 1. One-third octave band spectra of the stimuli: a) Reference R48, and different slopes; b) Octave band noises; c) Wide band noises, RC40, NC40; d) Speech shaped noises (SIIsp, SMS1, SMS2), phon48, and Ainv. Hearing threshold (HT) levels as well as the background (BG) noise levels are also depicted. The presented sounds were band limited to 100-10000 Hz.

2.5 Derivation of the penalty

Derivation of the penalty value k [dB] is presented in detail by Oliva et al. [2]. In short, penalty is an estimate of the level increase needed for neutral reference sound to be perceived as annoying as the studied sound. Thus, given a specific annoyance rating, the penalty is calculated as the difference between the actual measured L_{Aeq} level of the sound and an apparent L_{Aeq} level, looked up as the point of equal annoyance on the reference curve. The reference curve is obtained by fitting a linear function of the annoyance ratings of the reference sounds. The derivation of the penalty is exemplified in Fig. 2.

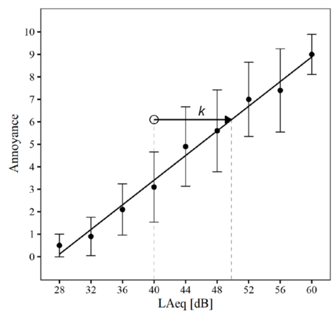

Figure 2. Mean annoyance ratings and 95 % confidence intervals of the reference sounds and example of the derivation of the penalty *k* for a sound with mean annoyance rating of 6.1 at 40 dB L_{Aeq}. In this example (HP1000) the penalty was 9.8 dB.

3. RESULTS

The results are illustrated in Figures 2–4. The annoyance ratings illustrated in Fig. 3 indicate that annoyance is increased with increasing L_{Aeq} level, and that annoyance also depends on the spectral shape. Considering the influence of spectrum, the results seem to support the previous findings [1] that sounds with proportionally more high than low frequencies (HP1000, o8000, p9dB, p6dB, o2000) are perceived overall as the most annoying. Here, the least annoying sounds were octave band noises o250 and o125, and low pass LP1000 as well as the speech shaped noises SMS1 and SMS2.

Figure 2 illustrates annoyance ratings of the reference sounds and the derivation of the penalty. The penalty values depicted in Fig. 4 further indicate the sounds containing relatively more high than low frequencies received greater penalty values than sounds that were more balanced or contained proportionally more low than high frequencies.

The lack of systematic pattern in the penalty values between L_{Aeq} levels indicate that, on average, L_{Aeq} level within 32–48 dB seems not to influence the penalty. This is an important finding since most sound levels measured indoors and outdoors in different living environments are close to this range and similar treatment can be proposed for all levels.

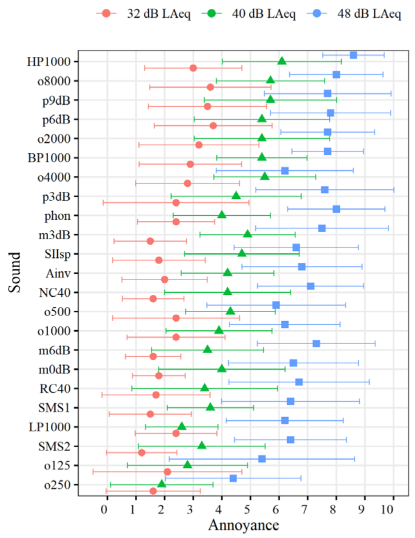

Figure 3. Mean annoyance ratings and standard deviations of the experimental sounds per each L_{Aeq} level.

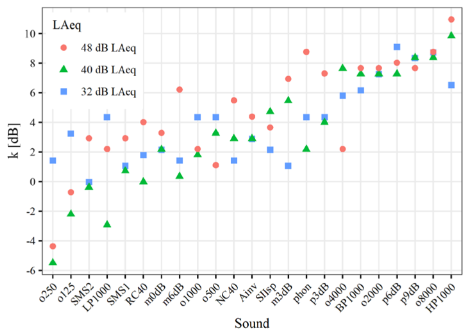

Figure 4. Penalties per each experimental sound and L_{Aeq}.

4. CONCLUSIONS

The influence of spectrum and sound level on subjective annoyance was studied with a psychoacoustic laboratory experiment. The experimental design also included the derivation of the spectrum related penalty. Results indicated that noise annoyance was affected by both sound level and spectrum. Penalty analysis indicated that spectral shape could result in a penalty of more than 10 dB, but L_{Aeq} level seems not to affect the penalty. The study shows that penalty should also be given for broadband steady-state sounds having a specific spectrum. The results can also be used in the development of comfortable masking sounds.

5. ACKNOWLEDGMENTS

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