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SEARCHING PHYSICAL CRITERIA OF SOUND QUALITY: PSYCHOACOUSTICAL STUDY ON THE SPECTRAL COMPOSITION OF DISCRETE-FREQUENCY NOISE

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ABSTRACT
The present work constitutes a first approach in studying the influence of the noise spectral composition on sound quality. With this aim, a psycho-acoustical test of noise annoyance has been achieved using unpleasant environmental discrete-frequency sounds. The initial sounds were modified in their spectral composition in different ways, but their acoustic level kept constant. Comparisons between differently modified sounds shows a significant and complex frequency influence on noise preferences.

1 - INTRODUCTION
For 20 years, technological improvements in noise reduction have provided powerful tools to control the noise pollution. However, their implementation shows that a reduction in noise acoustic level does not always correspond to an annoyance reduction [1,2]. Therefore the noise annoyance has to be considered as a more global concept than the acoustic noise level [3]. In that way, while numerous studies focus on improving the sound quality of a given product or phenomenon (e.g. [4,5]), we are interested in finding general physical criteria of sound quality, and more particularly of noise annoyance. The present study deals with discrete-frequency noise and focuses on the influence of spectral noise modifications on sound quality.

2 - EXPERIMENTAL SET-UP

2.1 - Acoustical stimuli
The acoustic material was obtained from four initial acoustic signals. These signals were chosen because of their subjective unpleasantness and physical characteristics (spectrum characterized by discrete components). They were extracted from recorded environmental sounds (from the CD "100 spectacular sound FX"): one domestic electrical machine noise (coffee grinder, comprising mostly low-frequency components), one jet engine noise (essentially mid-frequency components), and two alarm noises (fire alarm bell and alarm clock sounding, mostly high-frequency components). Thus, these four noises differ from each other by the frequency distribution of their spectral discrete components (fig. 1). In every case, the extracted signal duration was 1.5 s. An half-Hanning weighting (duration 0.1 s) was applied to the beginning and ending of the time signal, in order to reduce the hearing influence of the non stationary sound components.
Two types of processing are applied on the initial signals: spectral filtering or broadband noise addition. The spectral filtering is carried out in the frequency domain by direct and inverse Fourier transforms. It consists in either a 500 Hz high-pass filter, either a 2000 Hz high-pass, either a 2000-4000 Hz band cut, either a 4000 Hz low-pass, or a 8000 Hz low-pass. The second sound modification consists in adding

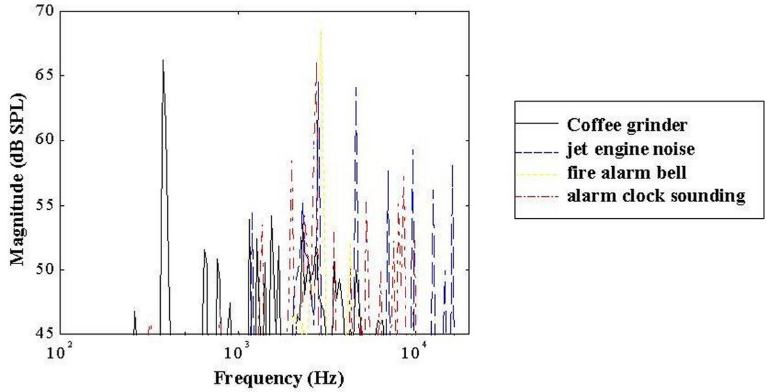

Figure 1: Spectra of the initial sounds.

broadband noise generated by inverse Fourier transform. Three different noises can be added: the first is "low"-frequency (100-1000 Hz), the second mid-frequency (2000-4000 Hz), and the third high-frequency (8000-12000 Hz).

The electrical signals equally fed both sides of a common stereo headphone (Technics RP-F290). The intensity of the different modified sounds is measured, and then the corresponding numerical signals are adjusted in their amplitude so that they provide a same acoustic level at the eardrum (80 dB SPL). The sound pressure level measurements were performed by a B&K microphone placed at the tympanum of an artificial ear of Zwilocki. For every signal considered, the difference between SPL and A level is inferior to 3 dB. Assuming the imperfection of the artificial ear and the middle ear contribution in the frequency filtering of the human ear, the different sounds would approximately correspond to a same A-weighted level measured in free field. Because of the discrete-frequency characteristics of the initial sounds, the masking between the different sound components would be reduced, and then a physical loudness estimation (by Zwicker's procedure [6]) provides results very close to each other for the filtered sounds.

2.2 - Subjects

Twenty-five subjects took part in the experiments. All the subjects, aged from 18 to 35 years, had normal audiometric functions (less than 20-dB loss between 125 and 8000 Hz, in octave steps on pure-tone audiograms). Except the two authors, they all had no experience on sound quality or psycho-acoustic tests. They all are French living in the same region, and then having a same cultural basis. Before the acoustic test, every subject filled a form of hyperacusia and a form of musical aptitude (musician or not, music preferences).

2.3 - Testing procedure

In order to assess sound quality, a subjective comparison of paired sounds was performed. The pairs are composed of one sound with and one without spectral modifications, both issued of a same initial acoustic signal. To compare the filtered signals (5 different filters), one obtains 10 combinations, and thus 10 pairs for each initial signal. For the noised signal (3 different masking noises), one obtains 6 pairs by the same way. The acoustic pairs presented to the subjects have a total duration of 3.75 s: first sound (1.5 s), separating silence (0.75 s), and second sound (1.5 s).

The testing procedure was the following: the subjects heard a pair of sounds and then had to choose the more pleasant of both; they can hear the pair again before choosing if necessary. Successively, for each of the 4 initial signals, each pair of modified sounds is presented in a randomized order. Each pair was presented twice to each subject (once in the order signal 1 − signal 2, and once in the order signal 2 − signal 1), to verify the reproducibility of the judgement and to avoid a bias linked to the order of the sound in the pair. The tests are implemented on a personal computer using MATLAB programming.

3 - RESULTS

As a first comment, the results are marked by a moderate intra-individual reproducibility of the judgement, which does not appears correlated with the order of the sound presentation. In accordance with the difficulty in choosing (voiced by the tested subjects), it indicates that the great spectral modifications applied to the sounds have just a low impact on the sound quality.

3.1 - Filtered signal assessment
The mean preferences, calculated on all the subjects, between the initial signal and the filtered signals are given in figure 2. For each tested sound, a Friedman repeated measures analysis of variance shows a statistically significant effect of frequency band removing on the sound preference ($p<0.05$). This filtering effect varies according to the spectral composition of the initial sound (fig. 2). For example, on one hand, for the coffee grinder noise (mostly low-frequency components), the low-frequency removing significantly improves the sound quality and the high-frequency removing decreases the sound quality (Tukey test, $p<0.05$). On the other hand, for the fire alarm bell (mostly high-frequency components), both low- and high-pass filtering result in a sound quality decrease ($p<0.05$).

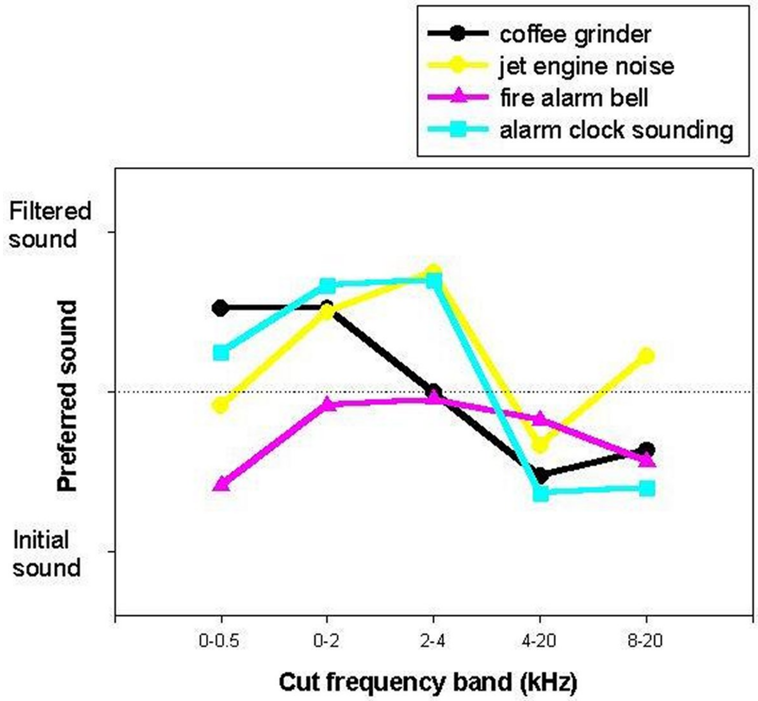

Figure 2: Means of the subjective assessment: comparison between the initial and filtered sounds.

3.2 - Noised signal assessment
Figure 3 shows the mean preferences between the initial signal and the signals mixed with broadband noises. As confirmed by statistical analysis, a significant effect of the frequency range of the added noise is noticed ($p<0.05$). The higher the masking noise frequency, the higher the sound quality, especially for the fire alarm sound, which essentially contains high frequency components.

4 - CONCLUSIONS
This preliminary study on unpleasant discrete-frequency environment sounds shows a low but significant influence of the spectral noise distribution on the acoustic annoyance. The greater improvement in noise quality was obtained on a mostly low-frequency noise by suppression of the low-frequency components and on a mostly high-frequency noise by a high-frequency broadband masking. In order to investigate accurately this complex influence of the spectral noise distribution, a more fundamental study using synthetic sounds is now in progress.

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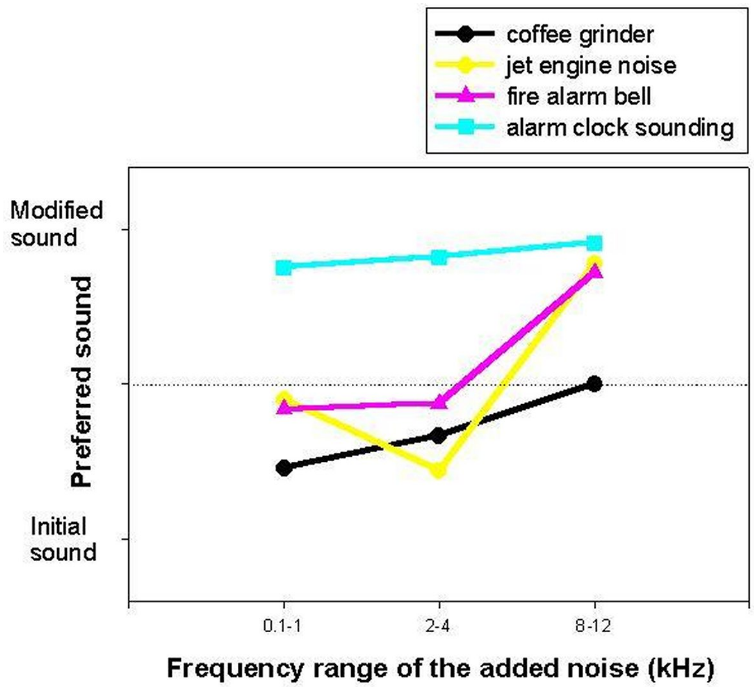

Figure 3: Means of the subjective assessment: comparison between the initial and noised sounds.

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