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Quantification of the unpleasantness of fan noise in the form of preference-equivalent levels

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Abstract

In a previous study by the authors, a semantic differential was used to rate a broad variety of fan sounds, which were equalized in A-weighted sound pressure level. A factor analyses of the results indicated six perceptual dimensions and five groups of sounds. The pleasant and the unpleasant fan sounds differed mainly with respect to the first three perceptual dimensions. A loudness analysis of the signals showed systematic differences in the patterns of the specific loudness for the different groups of sounds.

In the present study, loudness- and preference-equivalent levels were measured for typical sounds from the three major groups of sounds of the previous study. The results enable an interpretation of the findings obtained for sounds with equal A-weighted sound pressure levels in the form of level differences. It turns out that the group of unpleasant fan sounds needs to be reduced by 10 dB compared to the group of pleasant sounds based on median overall levels. Furthermore, level differences of up to 8 dB were found between the preference- and the loudness-equivalent levels for the group of unpleasant sounds. This difference is smaller for the two other tested groups of sounds.

Keywords: Fan noise, Preference, Pleasantness

1. Introduction

Fans are a part of many products of daily use and, thus, fan noise is a part of environmental noise that humans hear every day. In many cases, the technical application of fans for cooling or ventilation purposes is mandatory and the resulting noise can often not be avoided. Several studies already characterized fan noise based on listening tests. They showed that the evaluation of fan noise depends not only on the loudness of the sounds but other sound characteristics play also a role (1, 2, 3, 4). However, in listening tests exploring the perceptual space, the overall sound pressure level or loudness of the sounds is often equalized to reduce to the dominant impact of loudness differences on the evaluation and to capture the influence of sound characteristics other than loudness more clearly (5).

In a previous study by the authors, the perceptual space of fan sounds was explored with a semantic differential consisting of 29 adjective pairs, which were specifically composed for the characterization of fan sounds (4). Overall, 35 different fan sounds from eight different fan manufacturers and one research institute were rated by 45 participants in listening tests.

The application of a factor analyses to the results of the semantic differential data delivered six perceptual dimensions. The perceptual dimensions were characterized as I pleasant, II humming/bass, III shrill, IV monotone, V reverberant and VI noise-like. Similar perceptual dimension were also found by Feldmann *et al.* (1) for fan noise and by Sung *et al.* (2) for HVAC&R equipment. A second factor analysis delivered five groups consisting of sounds that were described and evaluated similarly. The mean semantic profiles of the three most important sound groups are shown in Figure 1. Based on their semantic profiles these sound groups were denoted unpleasant (A), humming (B) and pleasant (C). In that previous study, it was also possible to define psychoacoustic indices for a description of the most important perceptual dimensions, which are also relevant for the evaluation of the sounds.

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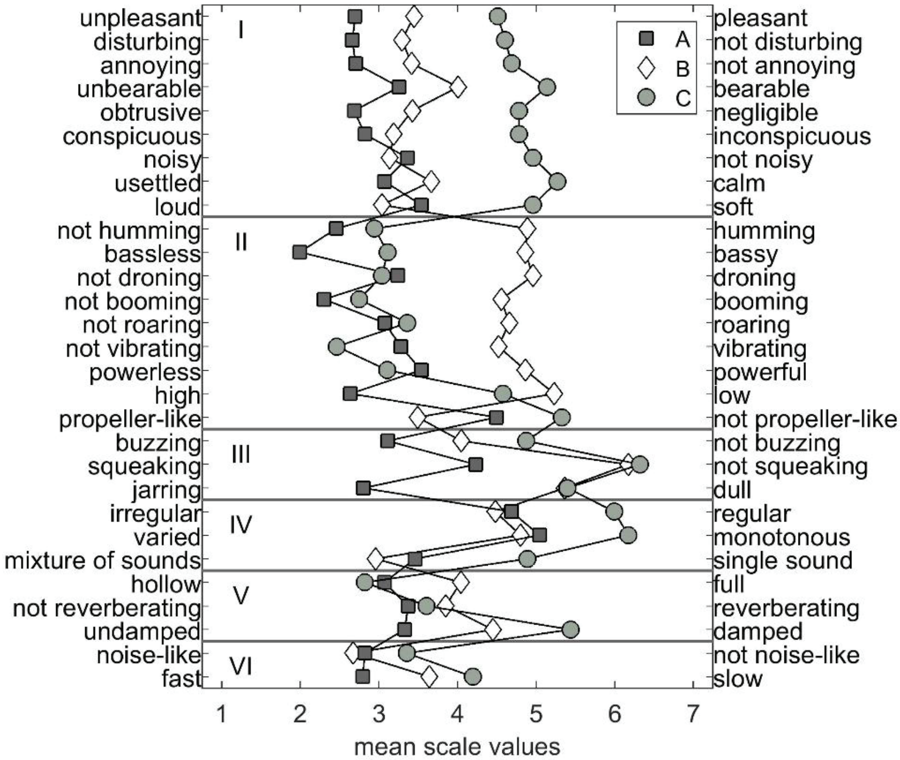

Figure 1 - Mean semantic profiles of the three most important groups of sounds (A unpleasant, B humming and C pleasant) plotted over the adjective pairs, ordered according to their loadings onto the six perceptual dimensions I-VI from the previous study (4).

To reduce prominent loudness differences and get an insight into the influence of the sound characteristics on the evaluation, the study with the semantic differential was based on sounds that were intentionally equalized to an overall A-weighted sound pressure level of 55 dB(A). However, the questions remains how the effects of different sound characteristics on judgments for level-equalized sounds translate to sounds which differ in original sound pressure level or loudness. Although the concept of level adjustments is used in many standards, only rather few knowledge on level equivalents for differences in sound evaluations is available.

The aim of the present study is a determination of points of subjective equality (PSEs) for loudness and for preference in separate listening experiments for selected sounds of the prior study. The PSEs were measured as loudness- and preference-equivalent levels compared to a fixed common reference sound as level differences on a dB-scale. In this way, differences between the pleasant and unpleasant sound groups from our prior study can be interpreted in terms of dB-differences.

2. Method

Points of subjective equality (PSEs) were measured with a two interval, two alternative forced choice paradigm varying the level of the test sounds with a 1-up, 1-down rule. The measurements are based on the assumption that an increase in overall level leads to a higher loudness and makes a test sound less preferred due to an increased unpleasantness (6). Following this assumption, the level of the test sound was increased, if the reference sound was louder, in the loudness experiment, or if the test sound was preferred, in the preference experiment. The level of the test sound was reduced, if it was judged to be louder (loudness experiment) or the reference sound was preferred (preference experiment). The reference sound was fixed to an A-weighted sound pressure level of 60 dB(A). In the preference experiments, the level changes were 6 dB at the beginning of an adaptive track, which were halved down to a value of 1.5 dB after each upper reversal point of the adaptive track. In the loudness experiments, the levels were initially changed by 3 dB, which was halved down to 1.5 dB after the second upper reversal. The adaptive procedure terminated after four reversal points with a step-width of 1.5 dB in both experiments. The PSEs were calculated as a mean value over these four reversal points. The adaptive tracks of six test sounds were interleaved in each experiment and the presentation order of the test and the reference sound was randomized in each trial.

2.1 Procedure

The listening tests for the 11 test signals were carried out in 5 sessions on different days together with 19 additional test signals. The results of the 19 other signals will be presented in another publication. Each session started by handing out written instructions to the participant. One-half of the participants always did the loudness experiment first, followed by the preference experiment. The other half carried out the experiments in opposite order. After each listening experiment, the participants took a short break and the experimenter recorded the first impressions mentioned by the participant. Each listening experiment had a duration of 20 to 30 minutes and a complete measurement session had a duration of about 90 minutes.

2.2 Stimuli

The 11 test signals were chosen as typical sounds from three groups of sounds of an earlier study (4), covering unpleasant (A1, A2 and A3), humming (B1, B2, B3 and B4) and pleasant (C1, C2, C3 and C4) fan sounds. Curves of the specific loudness for the test sounds and the reference sound for a common overall level of 60 dB(A) are given in Figure 2.

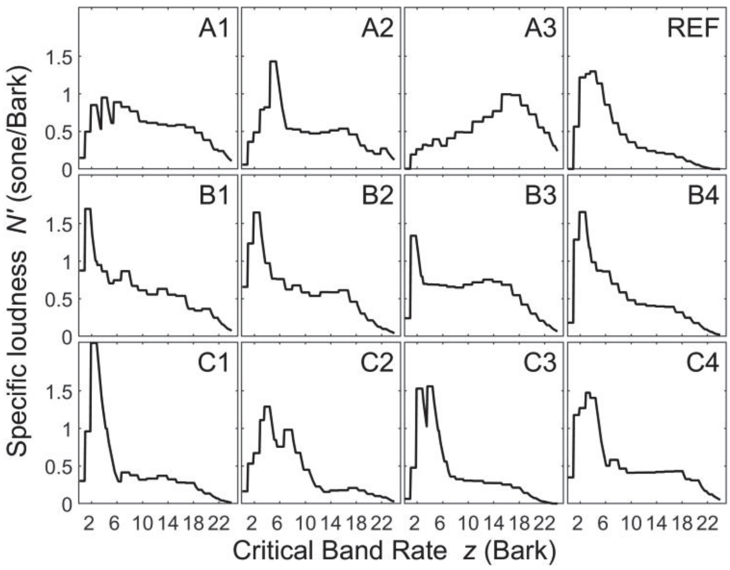

Figure 2 - Specific loudness curves of the 11 test sounds, which were selected from the three major groups of sounds (A unpleasant, B humming and C pleasant) from the earlier study (4), and the reference sound (REF) calculated according to the DIN 45631 for a common level of 60 dB(A).

The reference sound (REF) was based on a white noise signal, filtered by a second order high-pass with a cut-off frequency of 200 Hz and a second order low-pass with a cut-off frequency of 500 Hz. It was designed to be a rather pleasant and neutral signal, similar to the most pleasant fan noise from the prior study (C3 in Figure 2) and to have a rather high value of the index that was highest correlated to the pleasantness judgments (4). The major difference between the reference sound REF and sound C3 are two prominent tonal components, which are also visible as peaks in the specific loudness of C3. All sounds had a duration of three seconds. They were digitally stored with a sampling rate of 44100 Hz. The reference sound had a fixed A-weighted level of 60 dB(A). The level of the test sounds was 60 dB(A) at the beginning of each experiment and then varied according to the adaptive procedure.

2.3 Participants

Overall, 40 volunteers (20 female, 20 male) participated in the listening test. The mean age of the participants was 24 years (min=20 years, max=35 years). About 30 % of the participants did not have any experience with listening test. The other 70 % already participated in other listening test before. All of the participants reported no hearing problems. Each participant took part in five listening session on separate days and judged the 11 test signals presented here and 19 additional signals.

2.4 Apparatus

The listening experiments took place in a soundproof booth. The sounds were presented diotically over open headphones (Sennheiser HD650) that were driven by the headphone output of an external audio interface (RME Fireface UCX). The measurements of the PSEs were realized with the AFC-Toolbox (7) in Matlab (The Mathworks).

3. Results

Figure 3 shows the median points of subjective equality (PSEs) across participants from the loudness and the preference experiments for the eleven test sounds. All median PSEs are lower than the reference level of 60 dB(A), which means that level reductions were necessary for all test sounds to make them equally loud or equally preferred as the reference sound. The interquartile ranges, shown as error bars in Figure 3, are considerably smaller for the loudness PSEs than for the preference PSEs for all test sounds. Apparently, the loudness was judged more uniformly across participants whereas the preference PSEs indicate a considerable amount of inter-individual variability. This is especially the case for the sounds from Group A, which was characterized as the group of unpleasant sounds in the previous study (4).

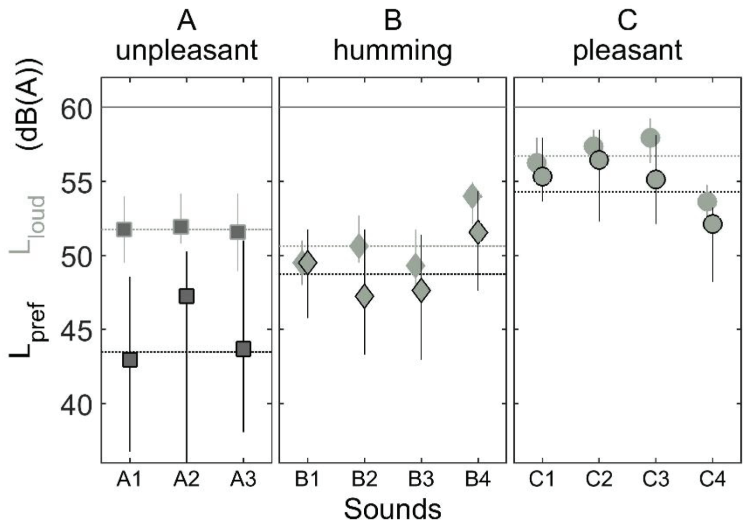

Figure 3 - Median points of subjective equality for loudness L_{loud} (grey) and for preference L_{pref} (black) for the 11 test sounds from the three major groups of sounds (A, B and C) compared to the reference sound with fixed level of 60 dB(A) (solid line). Group medians across the sounds of each group and across participants are indicated as grey (loudness) and black (preference) dotted horizontal lines.

The differences between the loudness-equivalent levels L_{loud} and the preference-equivalent levels L_{pref} are rather small (about 2 to 3 dB) for the sounds from the Group B (humming) and the Group C (pleasant) and the interquartile ranges overlap to a great extent for each of these test sounds. Thus, the preference evaluations seem to be tightly linked to the loudness judgments of the sounds for these two groups. For the sounds from Group A (unpleasant), the median PSEs for preference are up to 8 dB lower than the median PSEs for loudness. Apparently, an adjustment to equal loudness is not sufficient to make the sounds from Group A also equally preferred as the reference sound. This difference might be attributed to the unpleasant sound character of these test sounds, requiring larger attenuations of the test sounds to render them equally preferred as the reference sound (6).

Within each of the three groups of sounds, the median PSEs for preference L_{pref} for the individual sounds cover ranges of about 5 dB. For a better comparability of the groups, group medians (shown as dotted horizontal lines in Figure 3) were calculated for each participant across the respective sounds of a group individually and then across all participants. In terms of these total group medians across participants, the sounds from Group C need about 6 dB, the sounds from Group B need about 11 dB and the sounds from Group A need about 16 dB of level reduction compared to the reference sound.

The difference between the pleasant and the unpleasant fan sounds, which was on average about 2 scale values on the first perceptual dimension of the semantic differential data (see Figure 1), corresponds to a level difference between the group medians of about 10 dB in term the preference equivalent levels.

Acknowledgement

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