Loudness, noisiness, and annoyance of printer sounds

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Introduction

In order to achieve noise reduction at workplaces, laser or inkjet printers should be used. However, for administrative work, frequently a carbon copy is necessary, and therefore needle printers or daisywheel printers are usually applied. Therefore, noises produced by different needle as well as daisywheel printers, recorded in accordance with ISO 7779, were assessed in subjective experiments. The subjective evaluations are compared to physical measurements of loudness according to DIN 45631. In addition, questions of different methods (Semantic Differential versus Magnitude Estimation) and subjects from different countries (Japan versus Germany) are touched.

Experiments

The sounds of five different needle printers as well as two different daisywheel printers were recorded in an anechoic chamber according to the procedure described in ISO 7779 at the bystander's position. Sounds were presented diotically through electrodynamic headphones with freefield equalizers (Zwicker and Fastl 1999, p. 7). Fifteen Japanese subjects with an age between 21 and 52 years (median 28 years) and eight German subjects with an age between 25 and 44 years (median 26.5 years) participated in the experiments. From the Japanese subjects, five were female and ten male, all German subjects were male. The Japanese subjects performed an experiment of Semantic Differential (see Namba 1996) where each printer sound was presented three times in different sequence. The German subjects used a procedure of Magnitude Estimation and each printer sound was presented four times in random order.

Figure 1 shows the loudness-time functions of the sounds produced by printers A through G. Sounds C and D are produced by daisywheel printers, all other sounds by different needle printers.

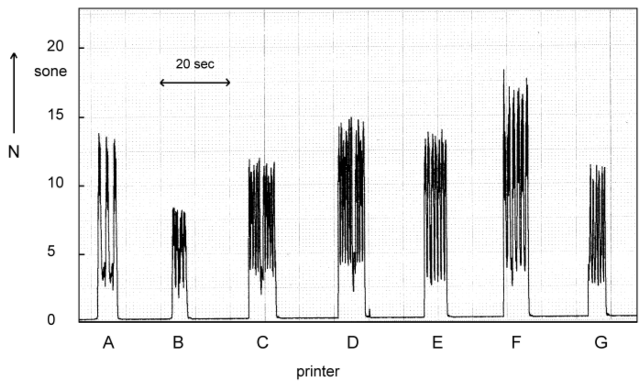

Figure 1: Loudness-time function of the sounds produced by the printers evaluated. C and D are daisywheel printers, all other printers are needle printers.

Results

Figure 2 shows the results of the Semantic Differential. The Japanese subjects evaluated 15 adjective scales (for detail see Namba 1996) for the seven printers A through G.

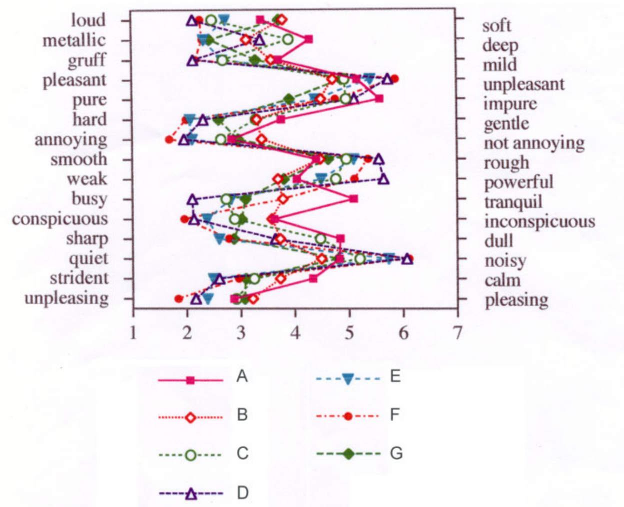

Figure 2: Semantic Differential for the sounds of the printers A through G.

The largest differences between the printer sounds occur for the adjectives 'busy-tranquil'. Sounds D and C are rated as rather busy whereas sounds A and B are rated tranquil. When regarding the related loudness-time functions in figure 1, it can be concluded that the number of peaks in the loudness-time function accounts for the adjective scale 'busy-tranquil'. Next, large differences between the printer sounds occur for the adjectives 'sharp-dull'. While needle printers E, F, G produce rather sharp sounds, the sharpness of the sounds produced by the daisywheel printers (C, D) is less aggressive. However, the needle printer A produces the sound with the smallest sharpness.

The smallest differences between the printer sounds are found for the adjective scale 'pleasant-unpleasant'. All printer sounds are clustered in the direction of 'unpleasant' which seems to be typical for this type of printer. However, it should be kept in mind that for the time being only needle and daisywheel printers can produce carbon copies which are legally acceptable.

The data displayed in figure 3 enable a closer inspection of the loudness, noisiness, and annoyance of the printer sounds studied.

The data displayed in figure 3a clearly show that the sound of printer F is louder than the sound of printer B (cf figure 1). Each histogram is based on 45 evaluations by 15 Japanese subjects. While the histogram for printer B (dashed) is centered around the neutral point (neither loud nor soft), the histogram for sound F indicates a considerably larger loudness. Both histograms are broadly tuned and in particular the histogram for sound B (dashed) extends the whole range from loud to

soft. This means that in particular for sound B the subjects have difficulties in reliably assessing its loudness.
Figure 3b shows the histograms for noisiness. The sound of printer F clearly shows more noisiness than the sound of printer B. Again, the histogram for sound B is more broadly tuned than the histogram for sound F.
In figure 3c, the histograms for annoyance are displayed. Sound F shows a larger annoyance than sound B, and again the distribution for sound B is more broadly tuned than the distribution for sound F.

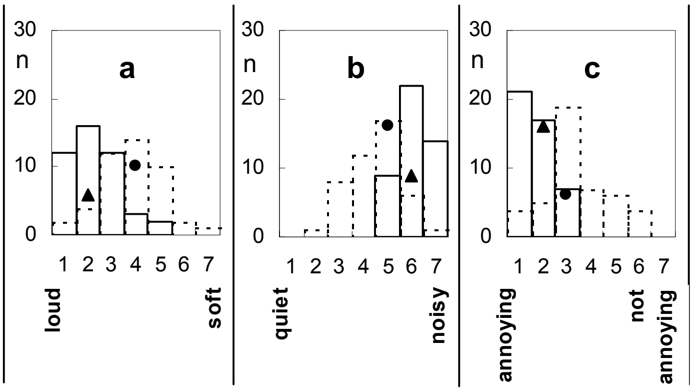

Figure 3: Histograms of ratings of printer sounds B (dashed) and F (solid) with respect to loudness (a), noisiness (b), and annoyance (c). Filled circles indicate medians for printer sound B, filled triangles medians for printer sound F.

The data displayed in figure 4 give an overview of the ranking of the printer sounds. Rank one stands for the loudest, noisiest, or most annoying sound. The ranking of the printer sounds derived from the experiment with Semantic Differential with 15 Japanese subjects is displayed by the filled circle for the adjective 'loud', by an open square for the adjective 'noisy', and by an open triangle for the adjective 'annoying'. The open circles represent data obtained for loudness by a procedure of Magnitude Estimations with eight German subjects. The asterisks indicate the ranking of physically measured loudness based on procedures described in DIN 45631.

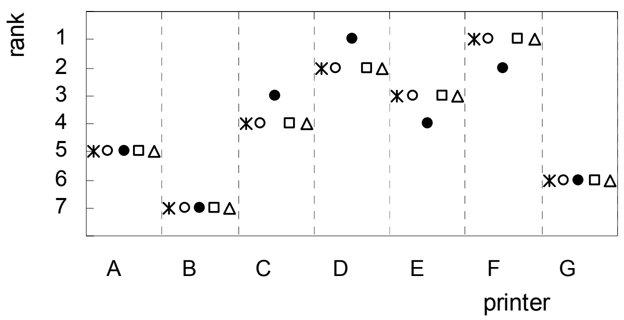

Figure 4: Ranking of the sounds of printers A through G.
Asterisk: physical measurement of loudness. Open circle: loudness evaluated by Magnitude Estimation with German subjects. Filled circle: loudness evaluated by Semantic Differential with Japanese subjects. Open square: noisiness evaluated by Semantic Differential with Japanese subjects. Open triangle: Annoyance evaluated by Semantic Differential with Japanese subjects.

The data displayed in figure 4 suggest that the ranking of physically measured loudness is in perfect agreement with subjectively evaluated noisiness (open square) and annoyance (open triangle) scaled by Japanese subjects as well as subjectively evaluated loudness (open circle) evaluated by German subjects. On the other hand, loudness evaluated by Japanese subjects with the method of Semantic Differential (filled circle) for sounds C, D, E, and F differ from the subjective evaluation of noisiness and annoyance as well as from physical evaluation. For Japanese subjects, the sounds from daisywheel printers (C, D) get a higher ranking in loudness than in noisiness or annoyance. On the other hand, for sounds E and F from needle printers, loudness is rated lower than annoyance or noisiness.
When calculating the rank correlation coefficient according to Spearman (Sachs 1973), there is perfect agreement between physical measurement and subjective evaluation ($r_S = 1.0$) for ratings of noisiness and annoyance by Japanese subjects as well as ratings of loudness by German subjects. For the loudness data obtained by Japanese subjects with the Semantic Differential, the rank correlation to physical measurements ($r_S = 0.929$) is still high and significant at the 0.5 % level. However, interestingly, for Japanese subjects the rank correlation between physically measured loudness and subjectively perceived noisiness or annoyance is still higher than the rank correlation with subjectively evaluated loudness.

Outlook

The data reported in this study clearly show that for sounds from printers which can produce carbon copies, the physically measured loudness based on DIN 45631 can be used as an excellent predictor for the ranking of noisiness and annoyance by Japanese subjects as well as loudness by German subjects. Despite the fact that the rank correlation ($r_S = 0.929$) between physically measured and subjectively evaluated loudness is also rather high for the Japanese subjects, it is of interest to further scrutinize the reasons for the small discrepancies.
We plan to check at least two hypothesis: 1. Influence of psychophysical procedure. It may well be that when applying a procedure of Magnitude Estimation also for the Japanese subjects, a perfect agreement of the subjective versus physical ranking of loudness may occur. 2. Our former studies (Namba et al. 1986) showed that the concept of loudness may be somewhat different in Germany and Japan. Frequently, everyday sounds which are called by German subjects as loud (*laut*) are labeled by Japanese subjects as noisy. 3. In future experiments, the printer sounds will be evaluated by the German subjects with the method of Semantic Differential. It has to be seen whether the adjectives 'loud', 'noisy', 'annoying' get the same ranking in perfect agreement with the ranking of physically measured loudness, or which differences will occur between the adjective scales, and whether or not they show high degrees of correlation with physical magnitudes.

Acknowledgements
This work was supported by the Japan Society for the Promotion of Science (JSPS).

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