Subjective impression of copy machine noises:
An examination of physical metrics for the evaluation of sound quality

Sonoko Kuwano[a]
Seiichiro Namba[b]
Osaka University

Osamu Takehira[c]
Ricoh Co. Ltd.

Hugo Fastl[d]
Technische Universitaet Muenchen

ABSTRACT

Copy machines are often used in offices where many people are working and their noises are desired not to be uncomfortable. Two experiments were conducted to examine the subjective impression of various copy machines and to find appropriate physical metrics to evaluate and predict the sound quality of copy machines. Experiment 1 was conducted in Japan, Germany and the U.S. using original sounds of copy machines. It was found that the value of L_{Aeq} has a large effect on the impression of copy machines. In order to find the effect of other physical parameters, Experiment 2 was conducted using the sounds with equal value of L_{Aeq}. Experiment 2 was conducted in Japan and Germany. It was suggested from the results of both experiments that L_{Aeq} and sharpness have a significant effect on sound quality and that CI (comfort index) composed of L_{Aeq} and sharpness seems a good index of sound quality.

[a] Email address: kuwano@see.eng.osaka-u.ac.jp
[b] Email address: namba.seiichiro @nifty.com
[c] Email address: osamu.takehira@nts.ricoh.co.jp
[d] Email address: fas@mmk.e-technik.tu-muenchen.de

1. INTRODUCTION

There are many machines in our surroundings and most of them generate sounds. If the sounds are undesirable, they become noise. It is desirable to improve the sound quality so that the bad impression of the noises may be reduced. In order to find effective countermeasures, it is necessary to find the physical parameters that show good correspondence with subjective impression. In this study sound quality of copy machines were examined to find appropriate physical metrics to evaluate and predict the sound quality of copy machines. Two experiments were conducted using original sounds from copy machines and their modified sounds. Since various factors are involved in the evaluation of the sound quality of machinery noises including cultural background of listeners, Experiment 1 was conducted at Osaka University in Japan, Ricoh branch office in San Jose in the US and Technische Universitaet Muenchen in Germany and Experiment 2 was conducted at Osaka University in Japan and Technische Universitaet Muenchen in Germany

2. EXPERIMENT 1

A. Stimulus

Seventeen kinds of sound from various copy machines were used for the experiment. All of them were original sounds without any modification and presented at the same sound levels as they were at the recorded position. Their sound levels varied from about 52 to 60 dB. The sounds were recorded in a semi-anechoic chamber according to the procedure described in ISO7779 at the bystander's position. The recorded sounds were edited so that at least one cycle of the copy is included. The duration was 6 s.

B. Procedure

Seventeen kinds of sound were presented to the participants in random order. The participants were requested to judge the impression of each sound using semantic differential. 16 kinds of seven-point adjective scales were used as shown in Figure 1 on the basis of the former studies[1]. The adjective scales are indicated in Japanese in the experiment in Japan and in English in the US and Germany. After training with two sounds, the participants repeated the experiment with different order of stimulus presentation. Three kinds of orders of adjective scales were prepared and each participant used one of them.

C. Equipment

The sounds were reproduced with a DAT recorder and presented to both ears of the participants through an amplifier, a free-field equalizer[2] and headphones (Beyer DT48) in a sound proof room. Similar equipment was used in the experiments in the three places.

D. Participants

Nine Japanese females and eleven Japanese males aged between 21 and 46 (average age 26.4 years old) participated in the experiment in Japan. Five American females and 10 American males aged between 31 and 59 (average age 45.1 years old) participated in the experiment in the US. Twenty German males aged between 22 and 42 (average age 26.6 years old) participated the experiment in Germany.

Hearing test was conducted with all the participants and the data of the participants who had normal hearing ability were used for the following analyses. In the experiment in the US, 20 people joined the experiment. However, the data of 5 participants were excluded due to their hearing ability. Therefore, the number of participants in the experiment in the US was 15.

E. Results and discussion.

The scale values of all participants were averaged for each trial of the experiment in each place. Coefficient of correlation between the first and the second trials was 0.901 in Japan, 0.797 in the US and 0.814 in Germany. These coefficients of correlations are significant and the judgments of the three places can be regarded as reliable. Therefore, the following analyses were conducted using 40 judgments in Japan and Germany, and 30 judgments in the US.

Generally speaking the subjective impression of sound quality judged in the three different places, Japan, the US and Germany, was similar to one another.

It was found that the stimuli Nos.5, 7 and 17 were judged as being neutral or a little better than neutral. An example of the profile is shown in Figure 1. The results of the three places are shown together in this figure; pink circles indicate the results in Japan, light blue squares Germany, dark blue triangles the US. On the other hand, stimuli Nos. 2, 4 and 14 were judged as being ugly, unpleasant, sharp, rough, metallic, etc. as an example is shown in Figure 2. These results suggest that there are fairly large differences in the sound quality among different copy machines and that there are little systematical differences among the three places in the subjective impression of sound quality of copy machines as far as the stimuli used in this experiment are concerned.
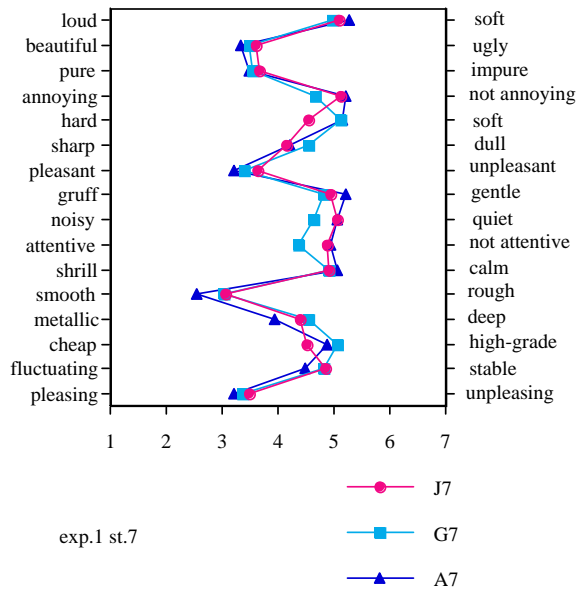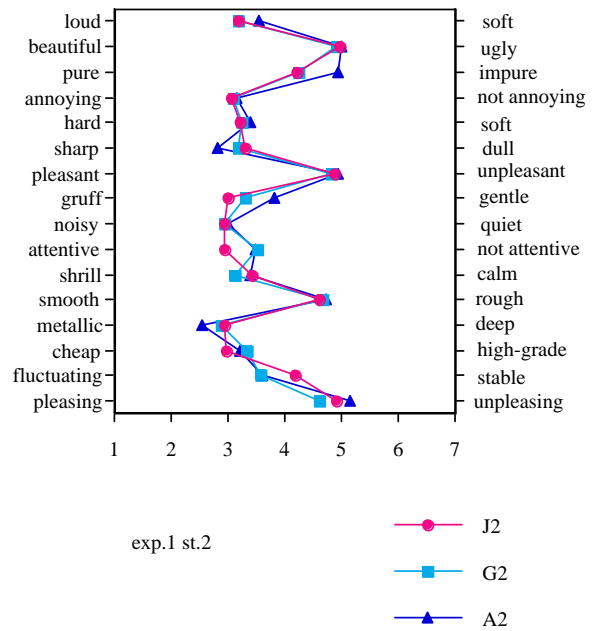

Figure 1

Figure 2

The adjective scale "pleasing – unpleasing" can be regarded as a representative scale of the impression of pleasantness and the relation between the scale values of "pleasing – unpleasing" and various sound quality indices ever proposed, such as L_{Aeq}, loudness, sharpness, roughness, fluctuation strength, impulsiveness and tonality[2], were examined.

It was found that L_{Aeq} and loudness showed good correlation with pleasant impression and calculated sharpness also showed fairly good correlation. A new index (comfort index: CI) defined by the following equation was proposed in our former study[3] ;

$$CI = 1/10 \; L_{Aeq} + \text{sharpness}$$
with L_{Aeq} in dB and sharpness in acum

As reported in our former studies[3-5], fairly good relation was found between the pleasant impression and CI. This index was examined with the results of the present experiment. The results are shown in Figures 3-5. It was found that this new index (CI) shows fairly good correlation with pleasant impression in the three places. This suggests that the new index may possibly be applied to predict the sound quality of various noises as the first approximation.

Since L_{Aeq} has a large effect on the subjective impression of sound quality of copy machine, Experiment 2 was conducted using the same stimuli as in Experiment 1 keeping the values of L_{Aeq} of all the sounds constant.
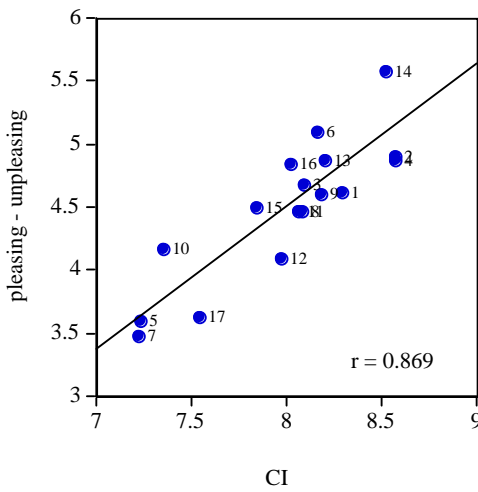
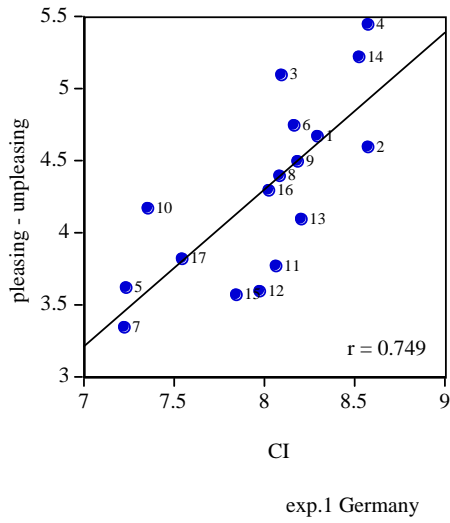exp.1 Japan

Figure 3

exp.1 US

Figure 4

CI

exp.1 Germany
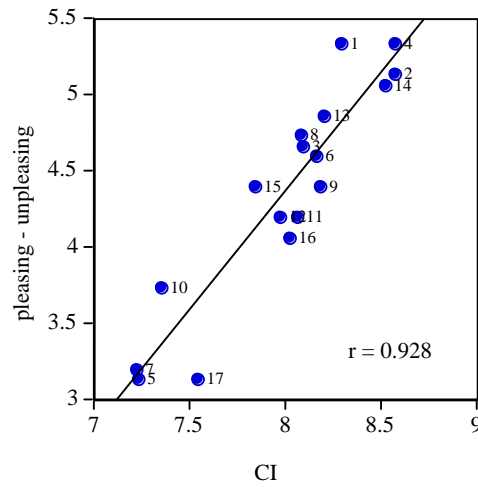
Figure 5

3. EXPERIMENT 2

A. Stimulus
The 17 sounds used in Experiment 1 were modified so that the values of L_{Aeq} of all the sounds were 56dB and used as stimuli in Experiment 2.

B. Procedure and equipment
The same procedure and the same equipment were used as in Experiment 1. Experiment 2 was conducted in Japan and Germany.

C. Participants
Eight Japanese females and twelve Japanese males aged between 20 and 47 (average age 26.4 years old) participated in the experiment in Japan. Twenty German males aged between 22 and 34 (average age 26.3 years old) participated in the experiment in Germany. All had normal hearing ability.

D. Results and discussion
The scale values of all participants were averaged for each trial of the experiment in each place. Coefficient of correlation between the first and the second trials was 0.780 in Japan and 0.849 in Germany. The judgments of the sounds with the equal values of L_{Aeq} seem not to be easy. However, the coefficients of correlations between two trials are significant and the judgments of the two places can be regarded as reliable. Therefore, the following analyses were conducted using 40 judgments in Japan and Germany.

Generally speaking, the impression of sound quality of the sounds was judged fairly neural since the values of L_{Aeq} of all the sounds were kept at 56.0 dB. However, there were some differences in the subjective impression among 17 sounds. Especially in Germany, some sounds were judged a little more pleasing than the other sounds. The relation between calculated sharpness and the pleasant impression was examined. The results are shown in Figures 6 and 7. Calculated sharpness showed better correlation with the scale values of "pleasing – unpleasing" with Germany participants than with Japanese participants. This suggests that German participants seem to be sensitive to high frequency components and tend to prefer the sounds with less sharpness. Since the values of L_{Aeq} were equal in all the sounds, the relation of CI (comfort index) with the pleasant impression is the same as that of sharpness.

4. FINAL REMARKS

The sound quality of copy machine was examined using semantic differential in Japan, the US and Germany. Seventeen kinds of the original sounds from copy machine were used in Experiment 1 and their modified sounds so that the values of L_{Aeq} were equal in Experiment 2. The results suggested as follows:
(1) There was little systematic difference in the subjective impression among in Japan, the US and Germany as far as the stimuli used in these experiments are concerned.
(2) L_{Aeq} and sharpness have important effects on the impression of sound quality.
(3) The new index (CI) that consists of L_{Aeq} and sharpness seem to be applicable to the evaluation of sound quality of the noise of copy machines.
   It was found that CI can be used for the evaluation of sound quality of various sounds. Further investigation is being planned how widely CI can be applied.

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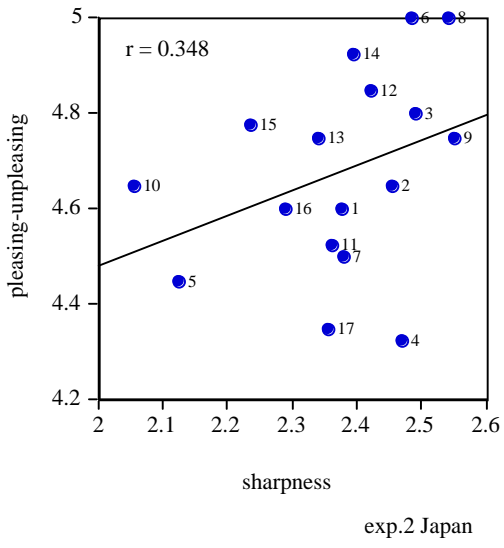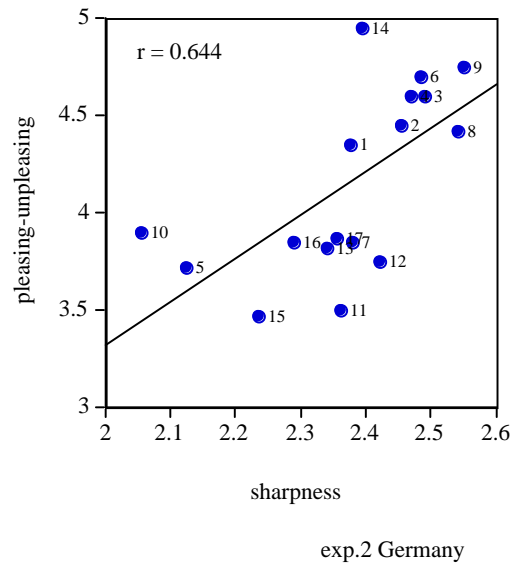
r = 0.348

exp.2 Japan

Figure 6

r = 0.644

exp.2 Germany

Figure 7