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Subjective Impression of Steady-state and Intermittent Sounds

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Abstract Subjective impression of steady-state and intermittent sounds was examined. The component sound of intermittent sounds has 30ms rise- and fall-time without steady-state portion and L_{Amax} was 70 dB. The carrier was white noise. The number of component sounds was varied from 5 to 80 in 4800ms total duration of the sound. The steady-state sound with the same duration was also used. The sound levels of the steady-state sounds were 53, 59 and 65 dBA. The loudness and the subjective impression of these sounds were judged using magnitude estimation and semantic differential, respectively, by fourteen German participants. The results showed that the loudness of intermittent sounds was judged louder than that of steady-state sound even if L_{Aeq} and L_{AE} values were equal. It was also found that the intermittent sounds were judged more annoying and unpleasant than steady-state sounds. These results suggest that affective impression has an effect even on the judgment of loudness.

1. INTRODUCTION

It is reported that L_{Aeq} is a good metric for the evaluation of temporally varying sounds [e.g. 1] and used as a basic metric in the environmental standards in many countries [2]. However, the subjective impression may differ depending on the temporal structure of the sound in the case of intermittent sounds. It would be better to examine the impression of intermittent sounds in reference to the total duration. When the total duration is shorter than 1 sec, the sounds can be perceived within the range of perceptual present [3] and it is reported that the intermittent sounds are perceived as being louder than steady-state sounds [4, 5] when the total energy is equal. This may be due to the dynamic characteristics of our hearing [6, 7]. A model of the dynamic characteristics of our hearing is shown in Fig.1 [6]. There is an overshoot at the onset, suppression in the middle and after-effect after the cessation of the

sound. When the silent intervals between component sounds in the intermittent sounds are short, the effect of overshoot and after-effect on the overall loudness may become great.

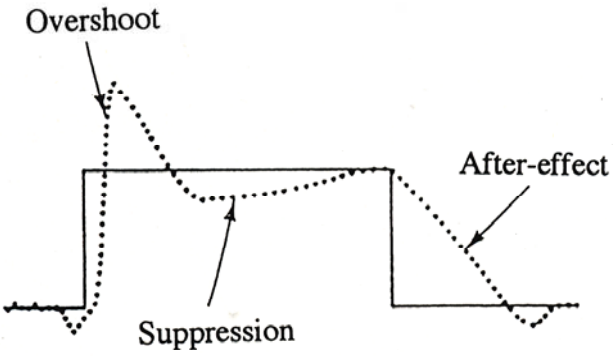


Fig.1 Dynamic characteristics of hearing [6]

When the total duration becomes longer, other factors may contribute to the judgment, such as cognitive factors and memory.

The duration becomes much longer in the case of actual intermittent sounds such as train noise or aircraft noise. In the former studies of Namba et al. , Fastl et al. and Kuwano et al. [8-12], the sounds of 9 –30 min were used and different numbers of events were included in the sounds. The results of these experiments are plotted together in Fig.2.

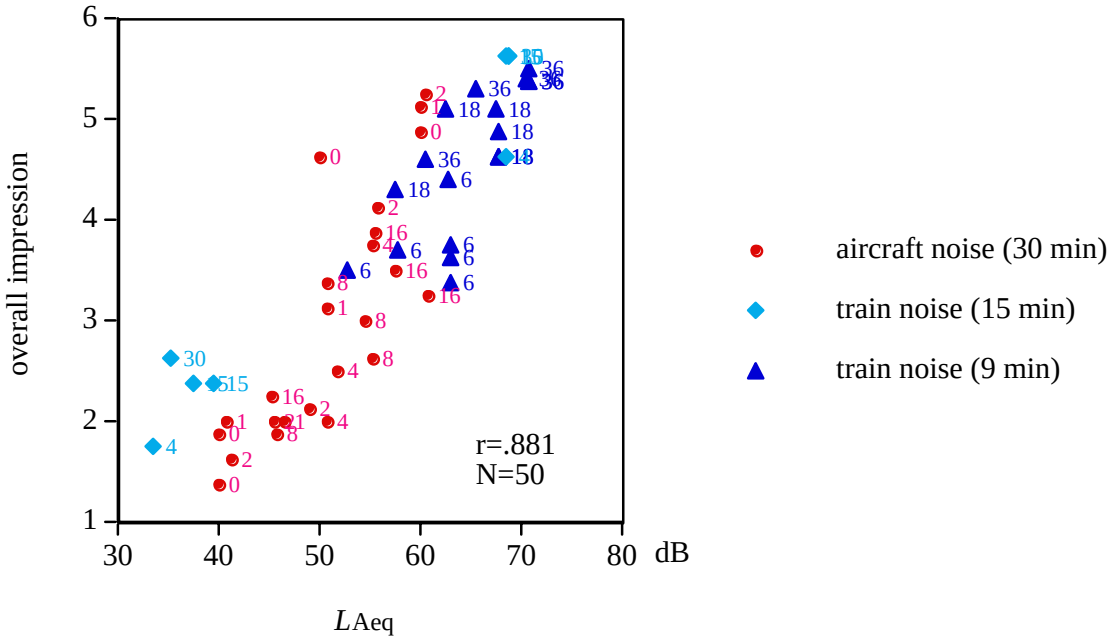


Fig.2 Relation between L_{Aeq} and overall impression of intermittent sounds. The number attached to each plot shows the number of events included in each sound.

It was found that L_{Aeq} is a good metric for the evaluation of these sounds as the first approximation though the coefficient of correlation is not so high as is usually found with the sounds of short duration. It should be noted that only intermittent sounds were used in these experiments and that they were not compared with steady-state sounds.

In this study, the subjective impression of steady-state and intermittent sounds was examined using synthesized sounds. In order to avoid the effect of the dynamic characteristics of hearing, the sound with 30 ms rise- and fall-time without steady-state portion was used as a component sound.

2. EXPERIMENT

2.1 Experiment 1

Loudness of intermittent and steady-state sounds was examined in Experiment 1.

Stimuli Six kinds of intermittent sounds and three kinds of steady state sound were used as stimuli. The component sound of intermittent sounds has 30ms rise- and fall-time without steady-state portion and L_{Amax} was 70 dB. The total duration of intermittent and steady-state sounds was 4800ms and the carrier was white noise. The stimulus conditions are shown in Table 1.

Table 1 Stimulus conditions

No.	I:Intermittent S: Steady-state	Number of component sounds	off-time (ms)	L_{AE} (dB)
1	I	5	900	60
2	I	10	420	63
3	I	20	180	66
4	I	40	30	69
5	I	60	20	71
6	I	80	0	72
7	S	-	-	60
8	S	-	-	66
9	S	-	-	72

Procedure The nine kinds of sound were presented in random order and the loudness was judged using magnitude estimation. The participants were requested to judge the loudness of each sound by assigning any positive number that they felt reflected the loudness. Three trials were conducted.

Equipment The sounds were reproduced with a DAT recorder and presented to the ears of the participants through an amplifier, a free-field equalizer and headphones in a sound proof

room in the Institute of Man-Machine-Communication of Technical University of Munich.

Participants Fourteen Geman males participated in the experiment. They were 30.6 years old on the average.

Results and discussion Coefficient of correlation between two trials among the three trials was calculated for each participant. Since statistically significant correlation was found with all the participants, the geometric mean of the 28 trials with 14 participants were calculated and related with *L*AE. The result is shown in Fig.3. There is a difference between intermittent and steady-state sounds. However, good correlation was found between *L*AE and the loudness for each group. At *L*AE below 70 dB, intermittent sounds were judged louder than steady-state sounds even if *L*AE values were equal. The difference became larger as the number of component sounds decreased in the intermittent sounds, i.e. as the interval between component sounds became longer. This result cannot be explained by the dynamic characteristics of hearing. Other factors may have an effect on the judgment of intermittent sounds than the energy of the sound and the dynamic characteristics of hearing. In order to examine the affective impression, the impression of these sounds was judged using semantic differential in Experiment 2.

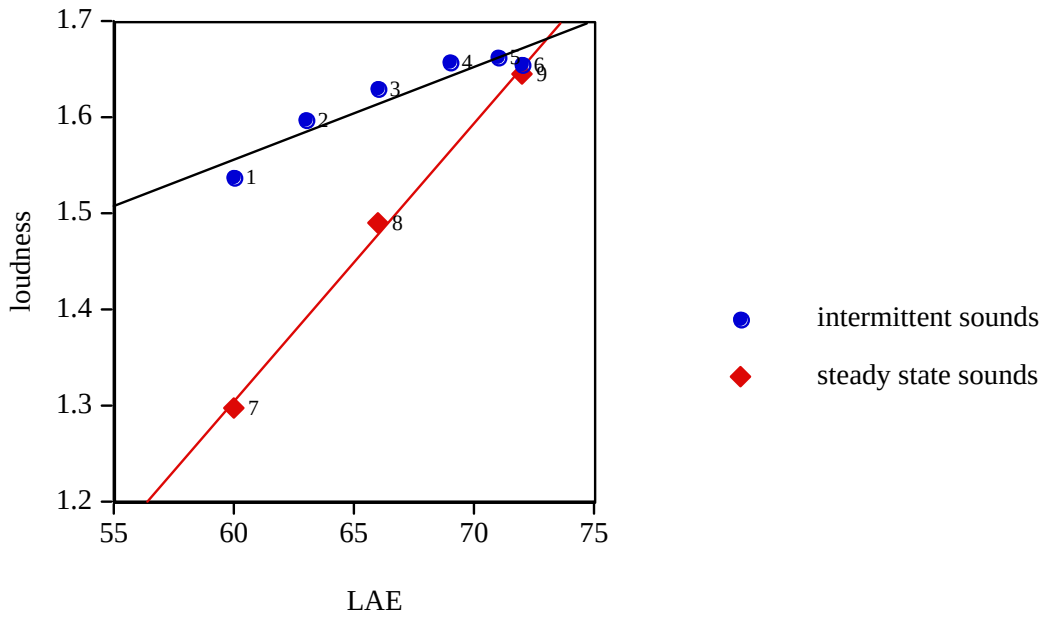


Fig.3 Result of Experiment 1

2.2 Experiment 2

The impression of intermittent and steady-state sounds was examined in Experiment 2.

Stimuli The same sounds were used in Experiment 2 as in Experiment 1.

Procedure The impression of the intermittent and steady-state sounds was judged using semantic differential. The sounds were presented in random order with the same equipment as in Experiment 1. The participants were requested to judge the impression of each sound using 7-point category scales of 13 adjective pairs shown in Fig.4. The adjective pairs were presented one by one on a computer monitor in random order.

Participants The same 14 participants as in Experiment 1 joined Experiment 2.

Results and discussion The judgments of 14 participants were averaged and the profiles of intermittent and steady-state sounds are shown in Figs.4 and 5.

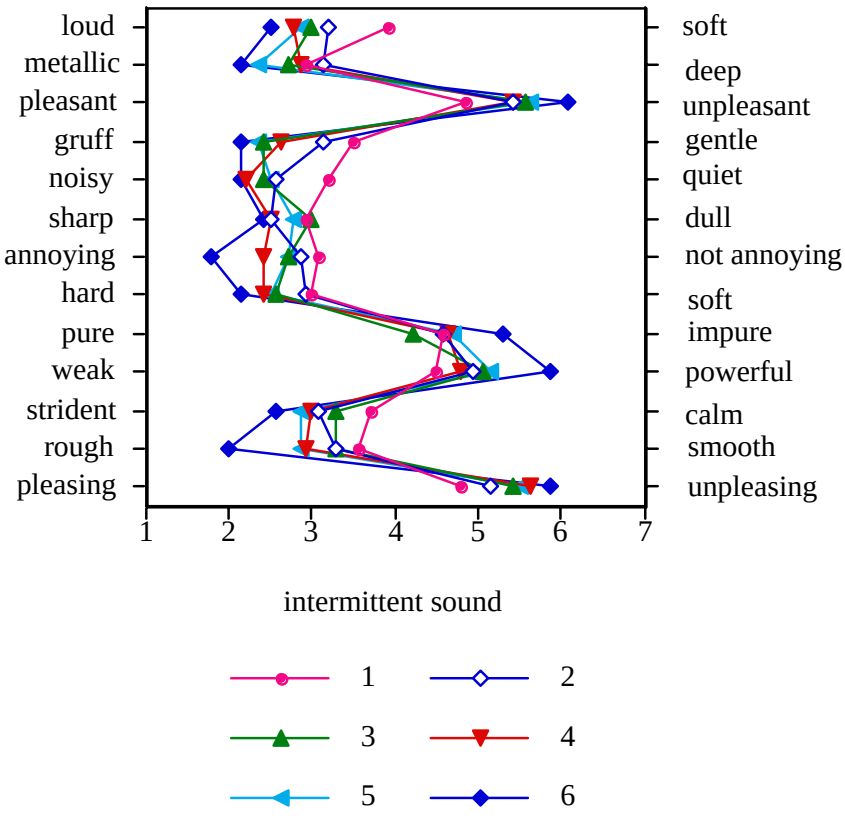


Fig. 4 Profiles of intermittent sounds

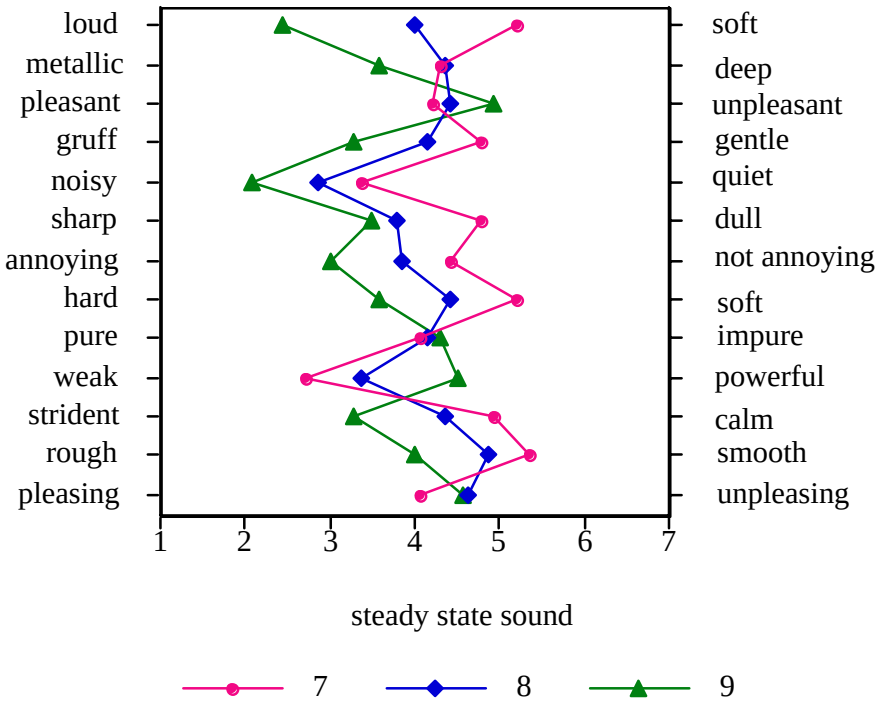


Fig.5 Profiles of steady-state sounds

Cluster analysis was conducted for the stimuli. The result is shown in Fig.6. It was found that intermittent sounds (Nos.1-6) and steady-state sounds (Nos.7-9) are divided into different groups and this suggests that their impression was judged differently. The profiles of intermittent and steady-state sounds are compared when their L_{AE} values are equal in Figs.7-9. It was found that intermittent sounds were perceived as being more unpleasant, annoying, powerful, sharp, rough, etc. than steady-state sounds. These results suggest that affective impression may have an effect even on the judgment of loudness.

There are many factors to be considered in the evaluation of intermittent sounds. One of them may be the relation between intermittent sounds and steady-state sounds. Among each group, total energy or mean energy level shows good correlation with subjective impression of loudness. However, there seems difference when they are compared with each other. Even if the values of L_{Aeq} or L_{AE} are the same, the impression of loudness was different between intermittent and steady-state sounds. This fact must be carefully considered when permissible level is decided for each of environmental sounds. Another factor may be the cognitive or affective effect. Though the sounds used in the present experiment were synthesized sounds, the affective impression showed a great difference between intermittent and steady-state sounds. Similar effect was found in our study of danger signals [13]. It was found that the repetition rate has a significant effect on the affective or dangerous impression. Also the total duration of the sounds may have a significant effect. Especially in the evaluation of actual environment, it is important to examine carefully when the length of the observation time period or reference time interval is decided. These factors have to be taken into consideration in the evaluation of intermittent sounds.

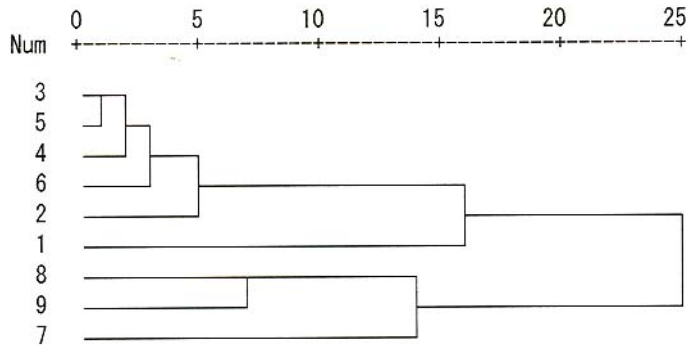


Fig.6 Result of cluster analysis

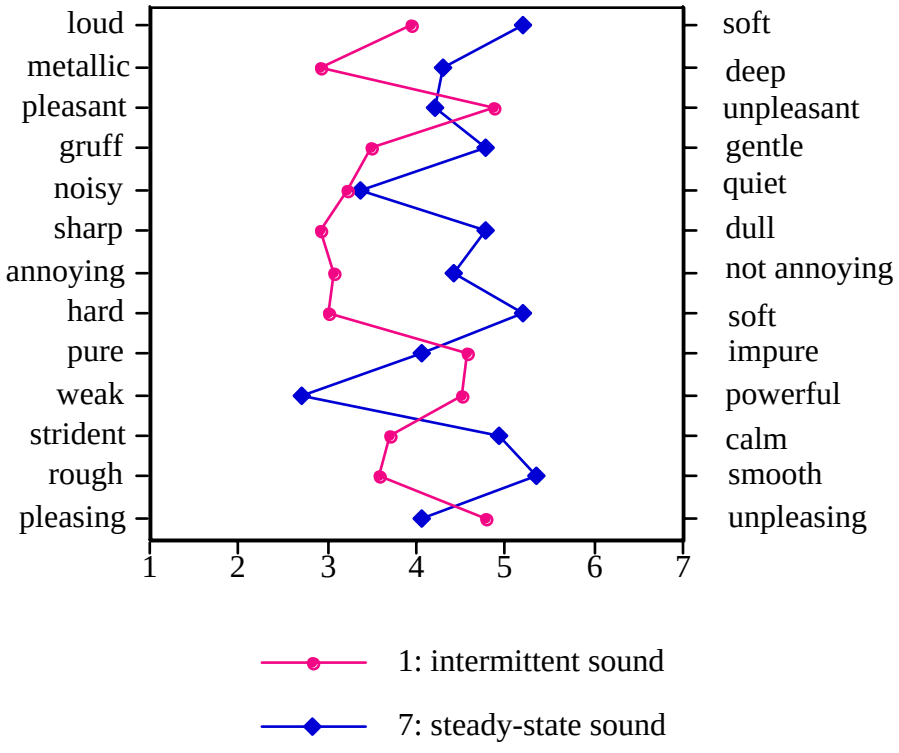
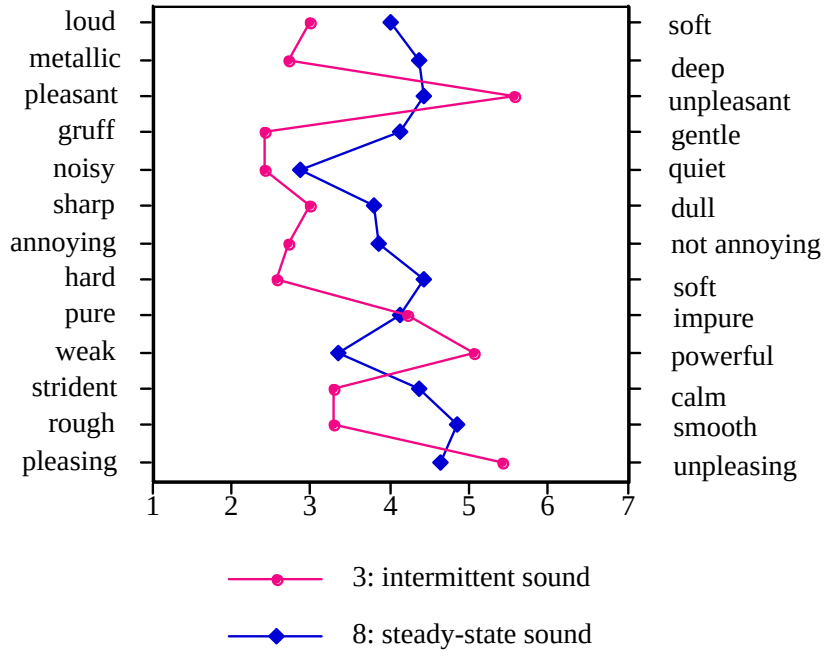
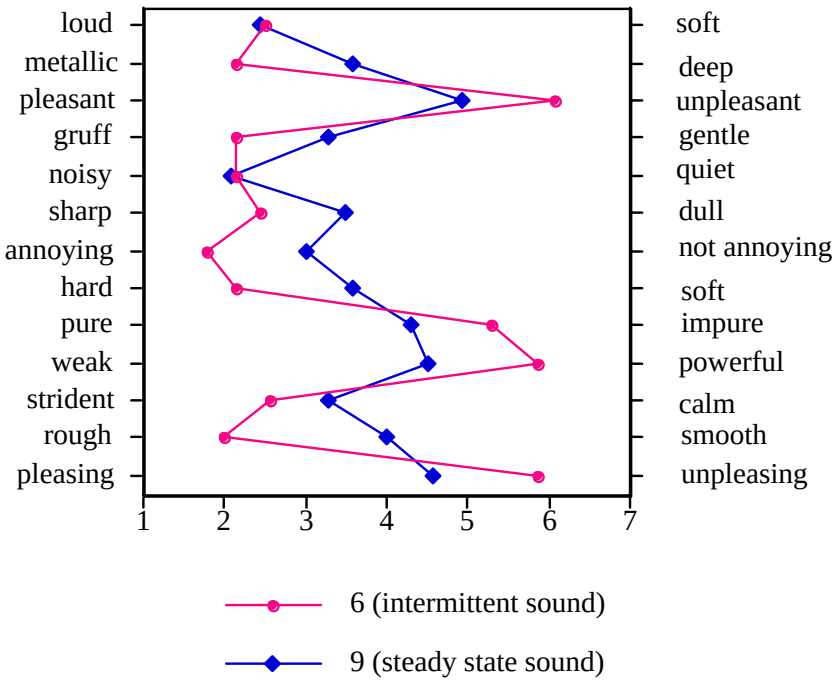


Fig.7 Profiles of the stimuli Nos.1 and 7



(LAE=66dB)

Fig.8 Profiles of the stimuli Nos.3 and8



(LAE=72dB)

Fig.9 Profiles of the stimuli Nos.6 and 9

3. FINAL REMARKS

When each of the intermittent and steady-state sounds is evaluated, total energy or the mean energy is a good metric to evaluate the sounds. However, when they are compared with each other, it was found that there is a difference in the impression between intermittent and steady-state sounds. Factors such as the dynamic characteristics of hearing, total duration, the silent interval between events, temporal pattern of sounds, affective impression, etc. may contribute to the difference. It is necessary to take these factors into consideration in the evaluation of intermittent sounds.

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