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Effect of temporal pattern of non-steady state sounds on loudness

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The effect of temporal pattern of non-steady state sounds on loudness was examined. In our previous study it was found that the temporal position of intensity increment has a systematic effect on the loudness of non-steady state sounds. The loudness was overestimated when the intensity increment was located at the onset or at the cessation of the stimulus. On the other hand the loudness was underestimated when the intensity increment was located in the middle. In our previous experiment, the stimuli were presented monaurally. In order to examine the mechanism of the effect, the stimuli were presented dichotically in the present experiment, *i.e.* the intensity increment was presented to the left ear and the rest to the right ear. The results showed no difference in loudness in different patterns except for in pattern 7 where the intensity increment was located at the cessation of the stimulus. This result suggests that the temporal effects found in our previous experiment is due to the effect of temporal masking. Further investigation will be needed in order to differentiate various temporal effects and examine more closely the dynamic characteristics of hearing.

Keywords: Loudness, Effect of temporal pattern, Non-steady state sound

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1. INTRODUCTION

We have been conducting experiments on the loudness of various impulsive sounds.[1-8] The results of our previous eight experiments are plotted together in Fig. 1.[9] It was suggested that the loudness of impulsive sounds can be approximated by the total energy, *i.e.* A-weighted sound exposure level, L_{AE}, as shown in Fig. 1.

However, precise examination of these results indicates that the temporal structure of stimuli has a significant effect on the loudness, though the effect is small. The effect of temporal structure was examined using non-steady state sounds, as an example. The temporal patterns of these non-steady state sounds are shown in Fig. 2. The temporal position of the intensity increment was systematically varied. The difference between loudness expressed by PSE and L_{AE} is shown in Fig. 3. Even if the total energy was equal, the loudness varied according to the difference of temporal structures. A model of the dynamic characteristics of hearing was proposed on the basis of the results of these experiments. As shown in Fig. 4, this model assumes overshoot at the onset of the stimulus, suppression in the middle, and after-effect at the cessation.

In our previous experiments the stimuli were presented monaurally, which means that the effect of masking on the result was considerable. When stimuli are presented dichotically, there is some central masking effect, but this is less significant than monaural masking. Therefore, in the present experiment the stimuli (shown in Fig. 2) were presented dichotically in order to examine the effect of temporal structures in detail.

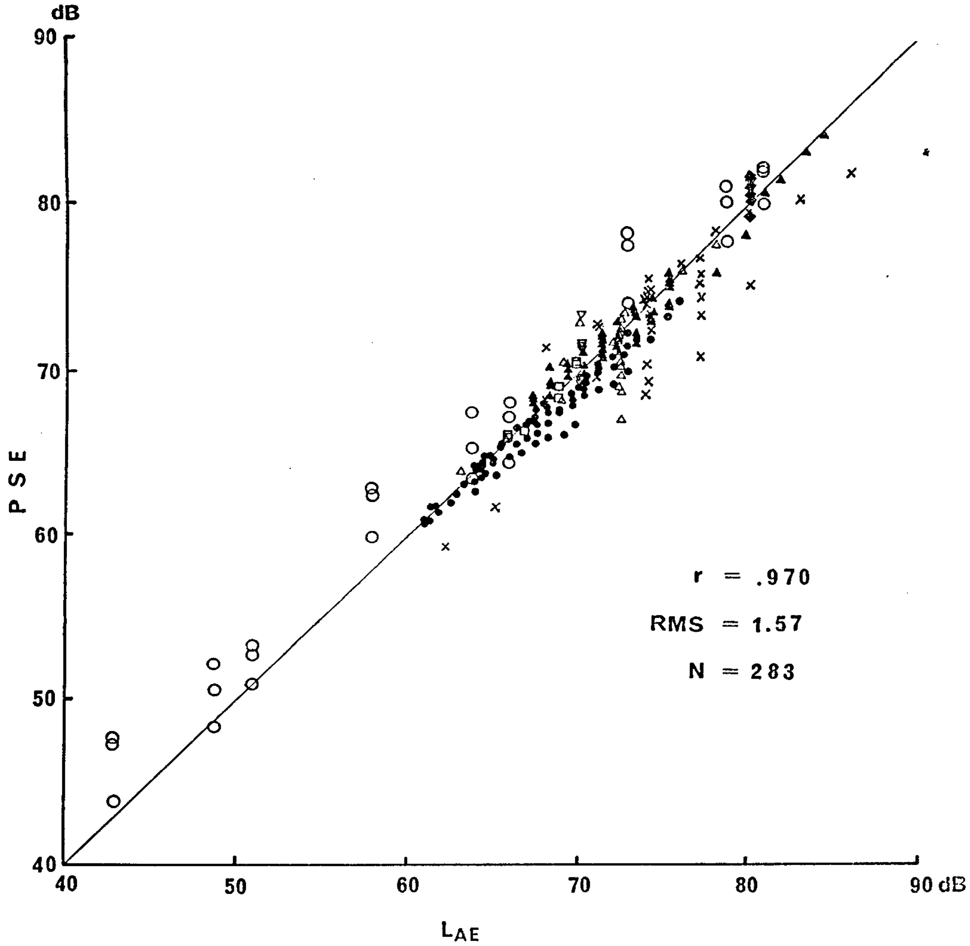

Fig. 1 The results of eight experiments on the loudness of impulsive sounds conducted by Namba *et al.* are plotted together. Good relation can be seen between L_{AE} and loudness expressed by PSE.

▲ Kuwano, Namba and Kato (1978)	impulsive sound with reverberation part
○ Namba, Kuwano and Kato (1974)	sound with rise time
□ Namba, Kuwano and Kato (1976)	sound with intensity increment (1)
● Namba and Kuwano (1981)	sound with intensity increment (2)
◆ Kuwano, Namba and Nakajima (1980)	impulsive sound with amplitude-modulated decaying part
▽ Nakajima, Kuwano and Namba (1979)	sound with rise time and sound with fall time
△ Nakajima, Kuwano and Namba (1980)	sound with intensity increment (3)
× Nakajima, Kuwano and Namba (1983)	sound with intensity increment (4)

$$L_{AE}=10\log\frac{1}{t_0}\int_{t_1}^{t_2}\frac{P_A^2(t)}{P_0^2}dt$$

where

$P_A(t)$ is the instantaneous A-weighted sound pressure; t_2-t_1 is a stated time interval long enough to encompass all significant sound of a state event; P_0 is the reference sound pressure (20 μPa); t_0 is the reference duration (1 s).

2. EXPERIMENT

2.1 Stimuli

Stimulus patterns are shown in Fig. 5. The higher-intensity component of each standard stimulus (Ss) was at a level of 83 dBA and 50 ms in duration (hatched section in Fig. 5). The rest was at a level of 80 dBA. The total duration of the whole stimulus was 350 ms. As comparison stimulus (Sc), steady state noise of 350 ms duration

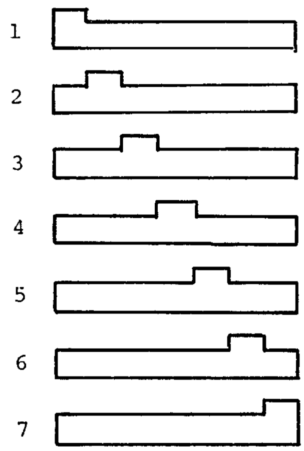

Fig. 2 The temporal patterns of non-steady state sounds. The intensity increment was systematically varied.

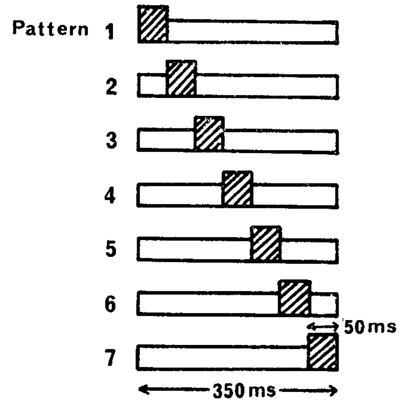

Fig. 5 The temporal pattern of the stimulus used in the present experiment. The higher-intensity component of the stimulus (hatched area) was presented to the left ear of the subject and the rest to the right ear.

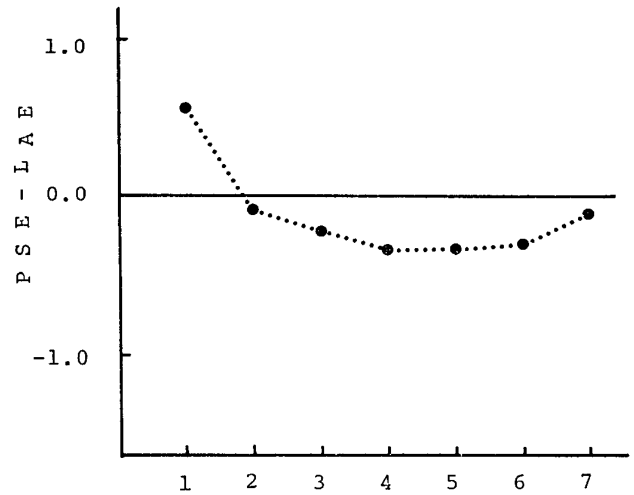

Fig. 3 It was found that the difference between PSE and L_{AE} systematically varied according to the temporal pattern of the stimulus.

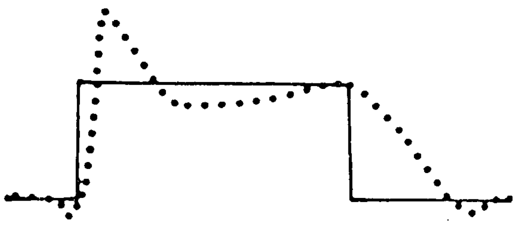

Fig. 4 A model of dynamic characteristics of hearing. The solid line indicates the physical stimulus pattern and the dotted line indicates the sensation. The model assumes overshoot at the onset of the stimulus, suppression in the middle, and after-effect at the cessation.

was used and its level was varied by 1 dB steps. White noise was used as a carrier.

2.2 Procedure

The higher-intensity component of each stimulus was presented to the left ear of the subject; the rest of Ss and Sc were presented to the right ear. The method of limit was used. Subjects were asked to judge whether Sc was perceived as being louder or softer in comparison with Ss. There was an interval of 1 s between pairs. Four trials, two ascending and two descending series, were conducted for each stimulus pattern. The order of stimulus presentation was randomized with each subject.

2.3 Apparatus

White noise was generated by a noise generator (Brüel & Kjaer 1405). After regulating duration, interval, and sound level using the Programmable Sound Control System II,[10] the stimuli were presented to the subjects through an amplifier (Yamaha CA XII) and headphones (TDH 49) in a sound-proof room.

2.4 Subjects

Five subjects, two females and three males with normal hearing ability, participated in the experiment.

3. RESULTS AND DISCUSSION

The point of subjective equality (PSE) was calculated by averaging 20 judgments by 5 subjects for each stimulus pattern. The results are shown in

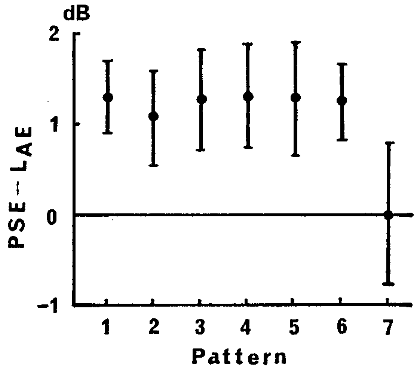

Fig. 6 The result of the present experiment. There is no significant differences in the loudness among the stimulus patterns except for pattern 7.

Fig. 6. There is no significant differences in the loudness among the stimulus patterns except for pattern 7, which was judged as being softer than any other pattern. This result is quite different from those of our previous experiments, where patterns 1 and 7 were judged as being louder than the other patterns.

A comparison of the results of our previous experiments, in which the presentation of stimuli was monaural, with the results of the present experiment, in which it was dichotic, suggests the following interpretation. The phenomena observed in our previous experiments may be due to the effect of temporal masking. That is, when the higher-intensity component is located at the onset or at the cessation of the stimulus, backward or forward masking occurs. On the other hand, when the higher-intensity component is located in the middle of the stimulus, both backward and forward masking occur. This may be the cause of the underestimation of the loudness of pattern 4 compared with the other patterns.

In the present experiment, because the stimuli were presented dichotically, the effect of masking was much smaller. This may erase the differences in the perception of loudness when the seven stimulus patterns were used. The reason why pattern 7 was judged as being softer than the other patterns is not clear.

Other factors concerning temporal effects in the perception of loudness should be taken into consideration. Namba *et al.*[11] have presented data which suggest the existence of overshoot at the onset of a stimulus and after-effect at its cessation. Fastl[12] has proposed a model of dynamic hearing sensation. It may be the case that there is interaction among backward, forward, and simultaneous masking. Further experiments will be needed in order to differentiate various temporal effects and examine more closely the dynamic characteristics of hearing.

REFERENCES

1) S. Namba, S. Kuwano, and T. Kato, "The relation between loudness and rise time as a function of energy," J. Acoust. Soc. Jpn. (J) **30**, 144–155 (1974) (in Japanese with English abstract).
2) S. Namba, S. Kuwano, and T. Kato, "The loudness of sound with intensity increment," Jpn. Psychol. Res. **18**, 63–72 (1976).
3) S. Kuwano, S. Namba, and T. Kato, "The loudness of impulsive sound," J. Acoust. Soc. Jpn. (J) **38**, 316–317 (1978) (in Japanese).
4) Y. Nakajima, S. Kuwano, and S. Namba, "The effect of duration on the loudness of steady-state sounds, sounds with rise-time, and sounds with fall-time," Proc. Autumn Meet. Acoust. Soc. Jpn., 603–604 (1979) (in Japanese).
5) S. Kuwano, S. Namba, and Y. Nakajima, "The effect of the shape of envelopes on the loudness of impulsive sounds with amplitude modulated decaying parts," Proc. Autumn Meet. Acoust. Soc. Jpn., 193–194 (1980) (in Japanese).
6) S. Namba and S. Kuwano, "Effects of temporal pattern of impulsive sounds on loudness," Stud. Hum. Soc. Sci. Coll. Gen. Educ. Osaka Univ. **29**, 1–15 (1981) (in Japanese with English abstract).
7) Y. Nakajima, S. Kuwano, and S. Namba, "The effect of temporal patterns of sound energy on the loudness of intensity increment sounds," Psychol. Res. **45**, 157–175 (1983).
8) S. Kuwano, S. Namba, H. Miura, and H. Tachibana, "Evaluation of the loudness of impulsive sounds using sound exposure level based on the results of a round robin test in Japan," J. Acoust. Soc. Jpn. (E) **8**, 241–247 (1987).
9) S. Kuwano and S. Namba, "On the dynamic characteristics of hearing and the loudness of impulsive sounds," Tech. Rep. Noise Acoust. Soc. Jpn. **N-8303-13**, 79–84 (1983) (in Japanese).
10) S. Namba and S. Kuwano, "Effects of temporal structure of masker on temporal masking. Appendix: Measurement of simultaneous masking using PSCS II," Tech. Rep. Hear. Acoust. Soc. Jpn. **H-84-1**, 1–6 (1984) (in Japanese).
11) S. Namba, T. Hashimoto, and C. C. Rice, "The loudness of decaying impulsive sounds," J. Sound Vib. **116**, 491–507 (1987).
12) H. Fastl, "Dynamic hearing sensations.—Facts and models," Tech. Rep. Hear. Acoust. Soc. Jpn. **H-84-13**, 1–6 (1984).