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ON THE EFFECTS OF TIME-VARIANT SOUND FIELDS ON SUBJECTIVE PREFERENCE

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Two experiments were performed to examine effects of modulated delay time of reflection on subjective preference. A time-variant model of an impulse response was applied for the sound stimuli. It consists of a direct sound and a single reflection whose delay time was modulated by a 0·1 Hz sinusoidal wave. The first experiment showed that the most preferred delay time of reflection is shortened when the delay time of reflection is modulated. It was found in the second experiment that the sound field with the modulated delay time of reflection is preferred to that with the fixed delay time of reflection especially in the case of performing changeful music with a small value of the effective duration of the autocorrelation function. Such a time-variant sound field may improve the subjective preference.

1. INTRODUCTION

1.1. BACKGROUND

Ueda and Ando reported that an air conditioner causes the fluctuation of sound pressure level (*SPL*) in a gymnasium [1]. Figure 1 shows the *SPL* values measured in the gymnasium using pure tones as sound sources. The *SPL* clearly fluctuates especially at higher frequencies when the air conditioner is on. Their results indicate that an indoor sound field can be regarded as a time-variant system. Not only a large room like a gymnasium but also any indoor sound field includes such a temporal fluctuation in the physical environment.

Based on statistical analysis of the *SPL* fluctuation, an acoustical model of a time-variant impulse response was proposed (see Figure 2). In this model, the impulse response is represented by a direct sound and modulated delay time of reflections. A simulation using the model showed the *SPL* fluctuation at higher frequencies as the measured data when the air conditioner was on.

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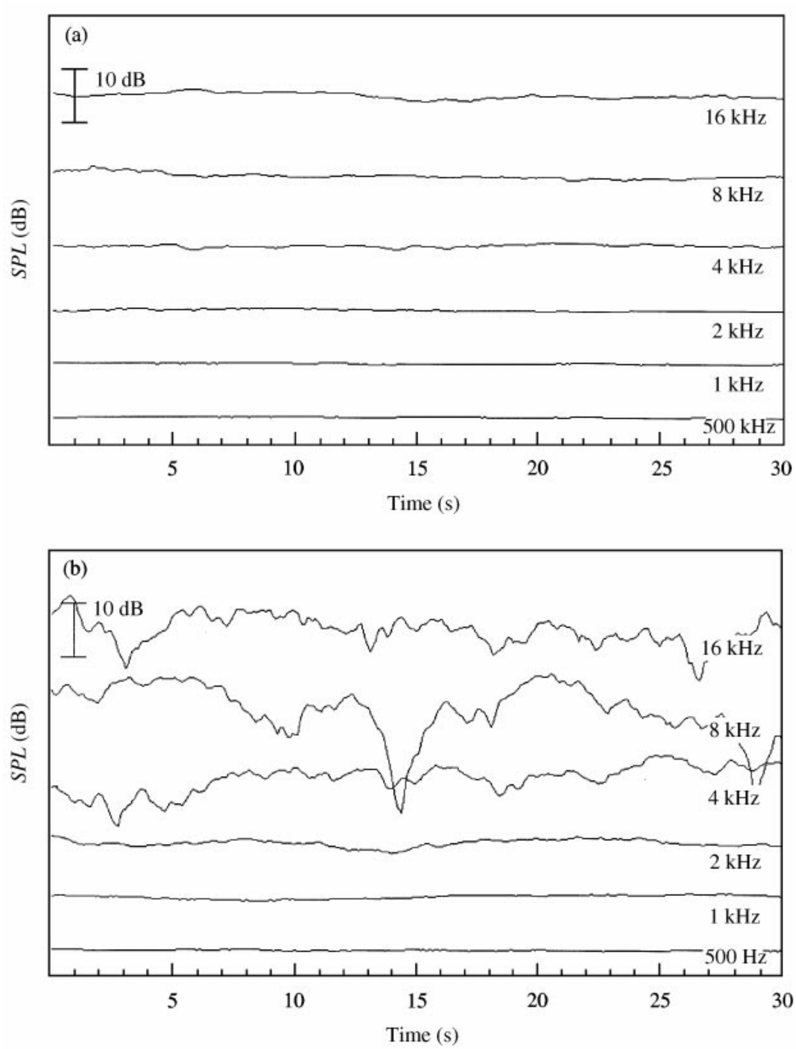

Figure 1. Comparison of the measured values of *SPL* in a gymnasium using pure tones as sound sources, in the cases of an air conditioner off (a) and on (b).

1.2. THE AIM OF THIS STUDY

In this study, two experiments were performed in order to examine the effects of a sinusoidal modulation of the delay time of reflection on subjective preference. The first experiment (Experiment 1) examined effects of the delay-time modulation on the most preferred delay time of reflection. The second experiment (Experiment 2) examined whether or not effects of the modulated delay time of reflection improve subjective preference.

2. EXPERIMENT 1

2.1. PROCEDURE

To observe effects of the effective duration of the autocorrelation function (ACF), two extreme musical sounds with different values of τ_e (see Table 1) were used as

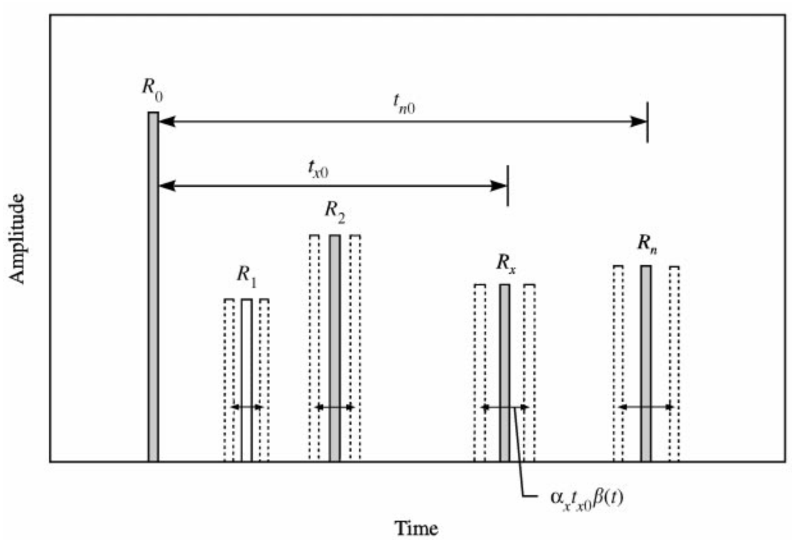

Figure 2. An acoustical model of the impulse response, which consists of a direct sound and modulated delay time of reflections, α_x: the change width of the delay time of reflection. $\beta(t)$: the change property of the delay time of reflection.

TABLE 1

Music sources used and the effective duration of the autocorrelation function (τ_e) *of source signals* [2]

Music source	τ_e (ms)
Motif A: Royal Pavane by Gibbons	127
Motif B: Sinfonietta by Malcolm Arnold	43

sound sources. The effective duration of ACF (τ_e) is defined as the time delay at which the envelope of the normalized ACF becomes 0·1 [2]. Motif A with larger value of τ_e contains more stationary features than motif B.

Figure 3 shows an acoustical model of the impulse response, which was applied in the experiment. It consists of a direct sound and the modulated delay time of a single reflection as representative of a set of reflections. It includes the definitions of the delay time of reflection (Δt_1) and the modulation interval of the delay time of reflection (Δ). The Δt_1 was modulated by a sinusoidal wave. The frequency of the sinusoidal wave was set to 0·1 Hz because it was observed to be 0·1–0·2 Hz from the analysis of *SPL* fluctuation in a real room [1].

As listed in Table 2, each motif has 10 stimuli in total with five different values for Δt_1 in the cases with fixed delay time of reflection ($\Delta = 0$) and with modulated delay time of reflection ($\Delta = 24$ ms for motif A and 30 ms for motif B).

The duration of a sound stimulus was set to about 10 s. The stimuli were paired and presented to subjects. The subjects judged which of the two sound stimuli was

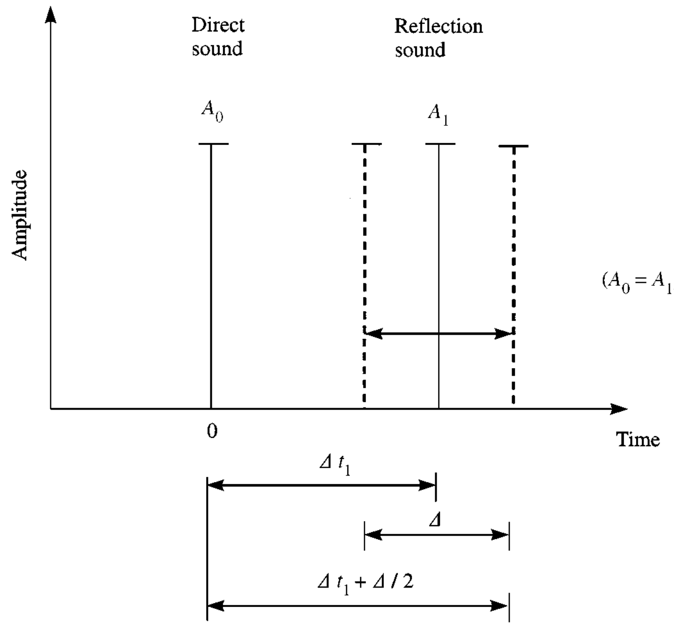

Figure 3. An acoustical model of the impulse response including the definitions of the delay time of reflection (Δt_1) and the modulation interval of delay time of reflection (Δ).

TABLE 2

Delay time of reflection (Δt_1) *and modulation interval* (Δ) *for each motif in Experiment* 1

Source	Δt_1 (ms)	Δ (ms)
Motif A	40, 60, 80, 120, 160	0, 24
Motif B	30, 40, 60, 80, 100	0, 30

more preferable to listen to. The experiment was carried out eight times repetitively for each subject. Four subjects aged from 23 to 30 participated in the experiment.

2.2. RESULTS

Figure 4 shows the mean scale values (SV) of subjective preference of all the subjects as a function of Δt_1 for each motif. As for motif A, the value of Δt_1 at the peak of SV is 120 ms in the case with the fixed delay time of reflection ($\Delta = 0$), and 80 ms in the case with the modulated delay time of reflection ($\Delta = 24$ ms). For motif B, the value of Δt_1 at the peak of SV is 60 ms in the case with $\Delta = 0$, and 40 ms in

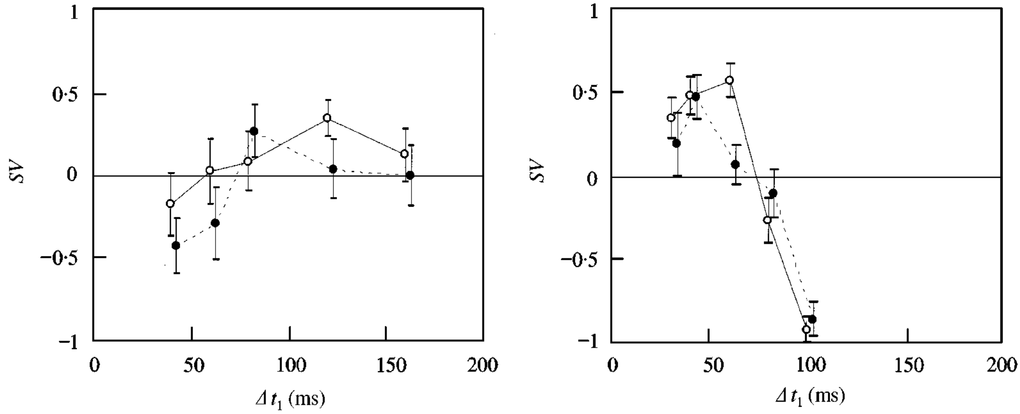

Figure 4. Mean scale values (SV) of subjective preference of all the subjects with the 95% confidence intervals as a function of Δt_1 for motif A (a) and motif B (b). ○, the mean scale values in sound fields with the fixed delay time of reflection ($\Delta = 0$); ●, those in sound fields with the modulated delay time of reflection ($\Delta = 24$ ms for motif A and 30 ms for motif B) by a 0·1 Hz sinusoidal wave.

the case with $\Delta = 30$ ms. These results show that the Δt_1 at the peak of SV in the cases with the modulated delay time of reflection are shorter than those in the cases with the fixed delay time of reflection.

3. EXPERIMENT 2

3.1. PROCEDURE

The sound field and sources were the same as those in Experiment 1. Each motif has six stimuli with six different values for modulation interval Δ as listed in Table 3. The initial delay time of reflection was set to 120 ms for motif A and 60 ms for motif B, which are the values at the peak of SV in the cases with the fixed delay time of reflection in Experiment 1. Three subjects aged from 23 to 30 participated in this experiment.

3.2. RESULTS

Figure 5 shows the mean scale values (SV) of subjective preference of all the subjects as a function of Δ for each motif. The figure for motif A shows that the SV at $\Delta = 8$ ms is a little larger than that at $\Delta = 0$. In the case of motif B, the SV at $\Delta = 15$ ms is significantly greater than that at $\Delta = 0$ ($p < 0{\cdot}05$).

4. DISCUSSION

The most preferred delay time of reflection ($[\Delta t_1]_p$) in a sound field with fixed delay time of reflection is described by the value of τ_e of a source signal and the amplitude of reflection relative to that of the direct sound A as follows [2]:

$$[\Delta t_1]_p \approx (1 - \log_{10} A)\tau_e. \qquad (1)$$

TABLE 3

Delay time of reflection (Δt_1) and modulation interval (Δ) for each motif in Experiment 2

Source	Δt_1 (ms)	Δ (ms)
Motif A	120	0, 8, 16, 24, 32, 40
Motif B	60	0, 15, 30, 45, 60, 70

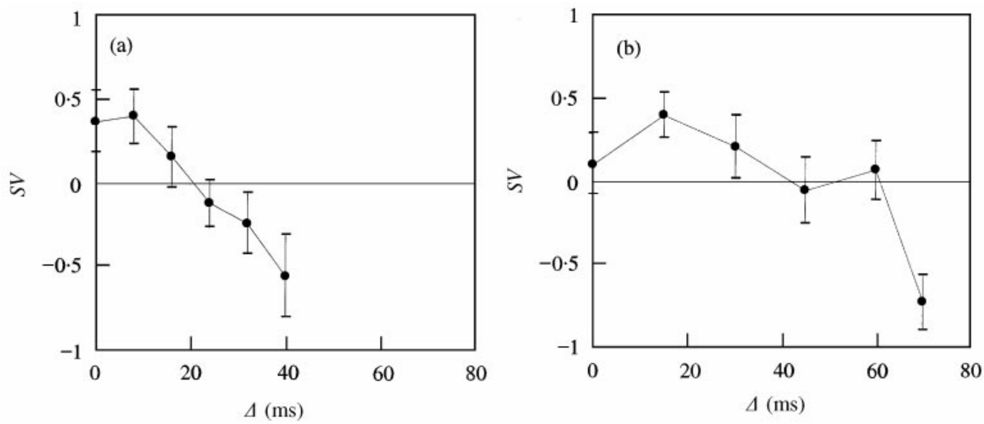

Figure 5. Mean scale values (SV) of subjective preference of all the subjects with the 95% confidence intervals as a function of Δ for motif A (a) and motif B (b). The delay time of reflection was modulated by a 0·1 Hz sinusoidal wave. The initial delay time of reflection was set to 120 ms for motif A and 60 ms for motif B.

The calculated values of $[\Delta t_1]_p$ are 127 ms for motif A and 43 ms for motif B as the amplitude of the single reflection is equal to that of the direct sound ($A = 1{\cdot}0$). Table 4 compares the most preferred delay times obtained from the regression curves of Figure 4 with those calculated by equation (1) in the sound field with the fixed delay time of reflection. The calculated values correspond well to the observed values and this correspondence supports previous studies [2, 3].

In a sound field with modulated delay time of reflection, the maximum delay ($\Delta t_1 + \Delta/2$) can be a cue to judge subjective preference; so, the Δt_1 in equation (1) is replaced by ($\Delta t_1 + \Delta/2$). Therefore, the $[\Delta t_1]_p$ in the sound field with modulated delay time of reflection becomes

$$[\Delta t_1]_p \approx (1 - \log_{10} A)\tau_e - \Delta/2. \tag{2}$$

Thus, for motif A, $[\Delta t_1 + \Delta/2]_p \approx 127$ ms and $[\Delta t_1]_p \approx 127 - 12 = 115$ ms; and for motif B, $[\Delta t_1 + \Delta/2]_p \approx 43$ ms and $[\Delta t_1]_p \approx 43 - 15 = 28$ ms. These values correspond well to the observed values in the case with the modulated delay time of reflection as listed in Table 4. Therefore, the effect of the modulated delay time of reflection was found that $[\Delta t_1]_p$ was shortened by $\Delta/2$.

TABLE 4

The most preferred delay times of reflection obtained from regression curves of Figure 4 and those calculated by equation (1) in the sound field with the fixed delay time and by equation (2) in the sound field with the modulated delay time

Source	Interpolated $[\Delta t_1]_p$ (ms)	Calculated $[\Delta t_1]_p$ (ms)
Fixed delay time		
Motif A	119	127
Motif B	44	43
Modulated delay time		
Motif A	103	115
Motif B	34	28

A positive effect of modulation interval Δ on subjective preference of motif B is found in Experiment 2, but such an effect on that of motif A is insignificant. A previous study found that the values of just noticeable difference of the modulation interval Δ for motif A are much smaller than those for motif B [4], so the subjects are more sensitive to the modulation in motif A than in motif B. It is considered that such a noticeable modulation for motif A may not improve the subjective preference.

5. CONCLUSIONS

When the delay time of reflection is modulated, the most preferred delay time of the reflection ($[\Delta t_1]_p$) is shortened by the half of modulation interval $\Delta/2$ although the sound sources with extremely different values of τ_e are used. The maximum value of delay time of reflection is significant to determine the subjective preference of delay time of reflection.

A time-variant sound field may have positive effects on subjective preference. This effect is more significant in the case of performing changeful music with a small value of τ_e.

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