Individual Preference in Relation to the Temporal and Spatial Factors of the Sound Field: Factors affecting Individual Differences in Subjective Preference Judgments

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Factors affecting individual differences in subjective preferences for various sound fields are discussed. The relations between temporal and spatial factors of sound fields and the individual differences in preferences for those fields were investigated by evaluating several characteristics of the 408 subjects in preference tests that were conducted in a sound simulation room over a period of four years. As the subjective preference for temporal factors is closely related to the effective duration of a sound source, ten different music pieces were used for the preference tests. The results show that, for each music piece, the most-preferred values of temporal factors can be predicted from the effective duration. Preference differences due to musical experiences were investigated by comparing the responses of test subjects with and without extensive musical experience. The experienced subjects preferred smaller values of temporal factors than did the inexperienced subjects did, and all subjects preferred sound fields with smaller IACC.

Keywords: subjective preference, individual differences, concert hall, spatial and temporal factors, musical experience

1. INTRODUCTION

When the acoustical quality of the sound fields in concert halls was evaluated in a series of experimental assessments of subjective preference, it was found that a total scale value of the subjective preference at any seat in a hall can be calculated when the values of orthogonal factors at the seat are known [1-3]. The four proposed orthogonal factors of a sound field are the listening level (LL), the initial time delay gap between the direct sound and the first reflection (Δt_1), the subsequent reverberation time (T_{sub}), and IACC (each is defined in Appendix A). The validity of the subjective preference theory based on cumulative results of psychological experiments using a number of subjects in simulated sound fields has been confirmed by tests in an actual concert hall and an opera theater [4, 5].

Subjective preference is accompanied by individual differences [2, 3]. As explained in Appendix A, the individual difference is identified by the most preferred value of each physical factor x_i (i = 1, 2, 3, 4) and the weighting coefficient α_i (i = 1, 2, 3, 4). Large individual differences are seen in the preferred initial time-delay gap and subsequent reverberation time, which are categorized as temporal factors. On the other hand, listening level and IACC, which are categorized as spatial factors, show few differences among individuals even when a music piece or its tempo changes. It is actually the effective duration, which is included in a source signal itself as a temporal cue, that largely determines the preferred conditions for the two temporal factors. One of the reasons that large individual differences appear in the temporal factors and not in the spatial factors is that the temporal factors influence an individualís brain during the time after birth in which oneís personality is formed more than the spatial factors do [3].

Intra-individual changes of preference judgments were also observed [6]. The subjects tended to have inconstant preferences with regard to the most preferred listening level x_1, and its weighting coefficient α_1 varied from one test series to another.

A seat selection system, implicitly testing the subjective preference of the experimental subjects, was arranged in a concert hall. The system outputs the preferred seat area for

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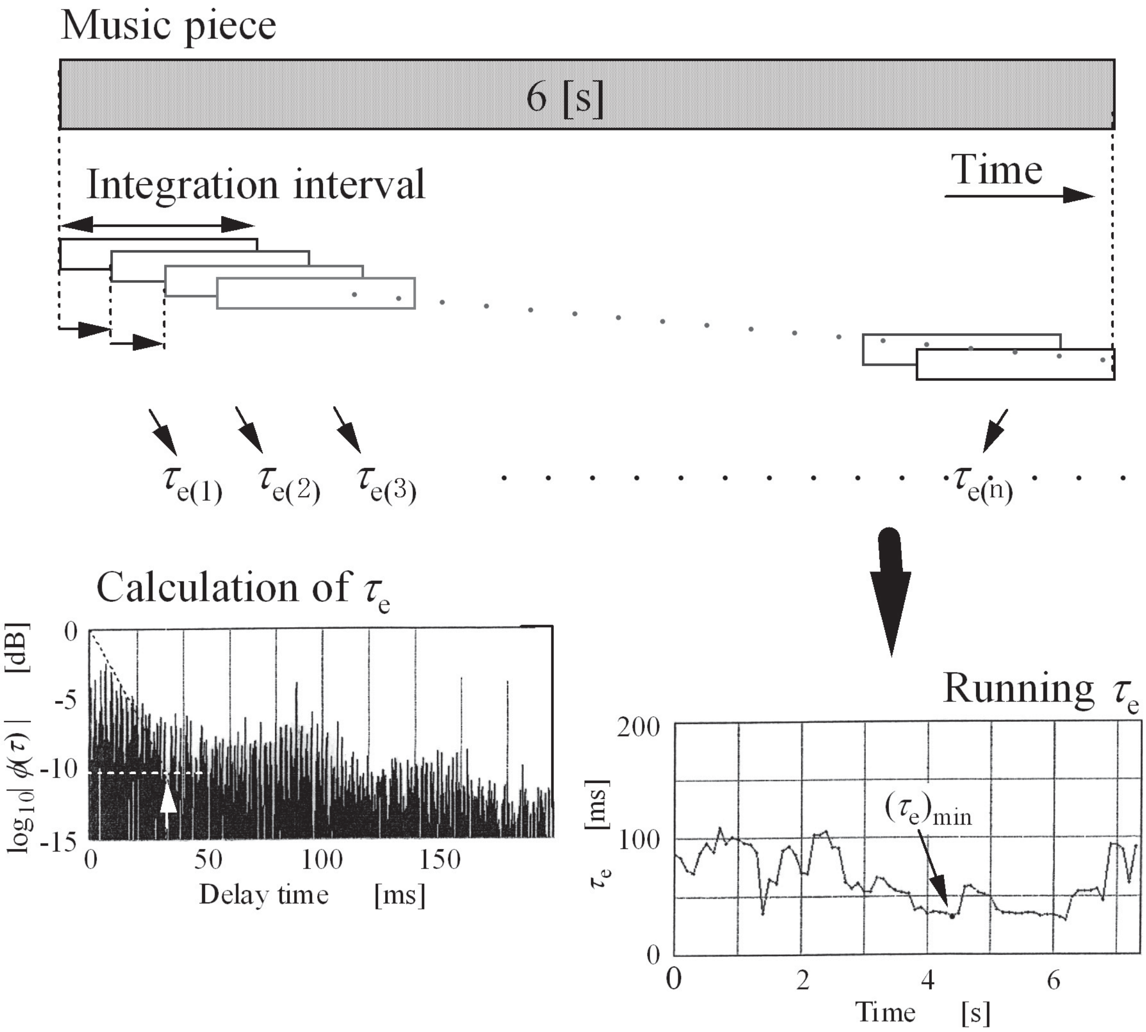

Fig. 1. An example calculation process of running τ_e and $(\tau_e)_{min}$ from a music piece. Each value of effective duration τ_e is calculated as a fine structure of the autocorrelation function of every integration interval 2*T*.

each individual after a 20-minute preference test [3, 7, 8].

Even in a concert hall, which satisfies the average preference of many people, it is quite important to satisfy the individual preferences of each listener. There are probably a number of factors influencing individual differences of preference, but none has been clearly identified yet. In the investigation dealt with in this paper, preference tests have been conducted continuously since 1997 using the seat-selection system. The individuals participating in those tests also filled out questionnaires specifying their musical experience. Here we focus on differences in their experiences and extract from the test results some factors affecting the individual differences in subjective preference.

2. EFFECTIVE DURATION IN RELATION TO PREFERRED TEMPORAL FACTORS

2.1. Effective Duration

Preferred temporal factors are related to an effective duration τ_e of a sound source. The effective duration is one of the fine structures of running autocorrelation functions (ACFs) of a sound source, and each music piece and each part has different values of effective duration (Fig. 1). Values of the effective duration can be obtained from running ACFs in every short period (say, 100 ms), and their minimum value $(\tau_e)_{min}$ can be obtained. This minimum value of τ_e, which represents the most active part among the music piece and is considered as a cue for preference-change of temporal factors, is calculated as follows.

Effective duration τ_e is obtained as a fine structure of an ACF with a certain integration interval. Its value is defined by the ten-percentile delay (at -10 dB), obtained from the initial decay rate extrapolated in the range from 0 dB to -5 dB of normalized ACF on a decibel scale. The $(\tau_e)_{min}$ is obtained as the minimum value among running τ_e values calculated for

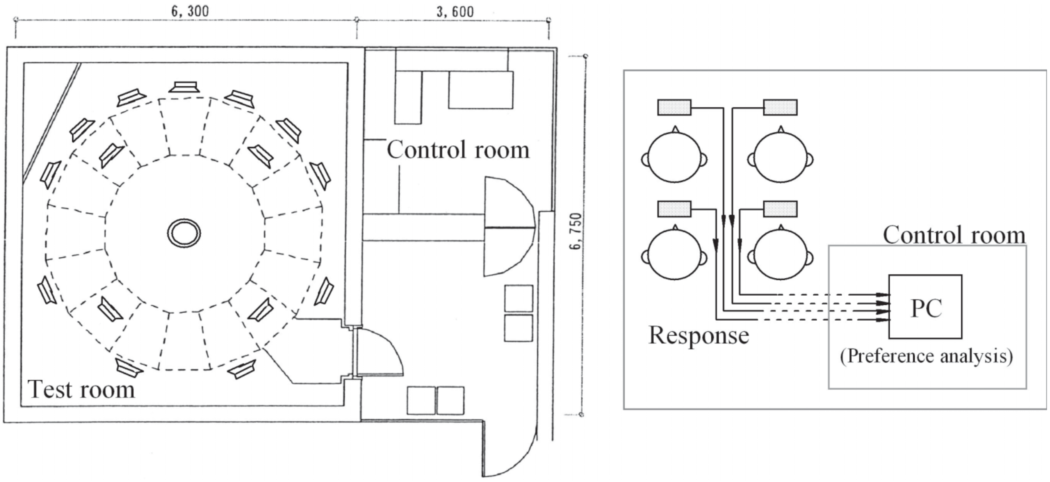

Fig. 2. Plan of the anechoic room for the subjective preference test. The system is installed at the Kirishima International Concert Hall (Kirishima, Japan).

every 100 ms for each music piece.

The recommended integration interval (2T) [9] was proposed as

$$2T \approx 30(\tau_e)_{min}. \quad (1)$$

And its value is determined after some iteration (the initial value of 2T is about 2 s, which corresponds to the psychological present [9] in listening to music).

2.2. Preferred Temporal Factors in terms of $(\tau_e)_{min}$

The sound fields reproduced for subjects during preference tests were set up around the center of preferred values for the average listener. The preferred values of temporal factors for sound fields were calculated by using $(\tau_e)_{min}$ value.

The preferred initial time-delay gap $[\Delta t_1]_p$ can be calculated as:

$$\tau_p = [\Delta t_1]_p \approx (1 - \log_{10}A)(\tau_e)_{min}, \quad (2)$$

where A is total amplitude of reflections (in these tests, the value of A was constant: 4.0). Sound fields of Δt_1 were set as 1/4, 1/2, 1, 2, and 4 times x_2, which is specified by Equation (A4) in Appendix A.

The preferred subsequent reverberation time $[T_{sub}]_p$ was calculated as follows:

$$[T_{sub}]_p \approx 23(\tau_e)_{min}. \quad (3)$$

As was done with Δt_1 , sound fields of T_{sub} were set as 1/4, 1/2, 1, 2, and 4 times x_3.

3. EXPERIMENTAL CONDITIONS

3.1. Room for the Measurement and Preference Test

Preference tests were conducted in the sound simulation room in the Kirishima International Concert Hall (Kirishima, Japan) from 1997 to 2000. The plan of the anechoic room for the subjective preference test (test room) is shown in Fig. 2. The test room is 5.2 m in diameter and 3.1 m high at its center. Sixteen loudspeakers are arranged around the room for reproduction of simulated sound fields, which are produced by using dry sources after passing them through digital delay units and digital reverberation units controlled by MIDI.

3.2. Subjects

A total of 408 musicians, visitors to the hall, and students participated in preference tests as subjects. Most of the reference tests investigating the influence of the musical experience were conducted during the annual international music festival in summer.

3.3. Sound Source

Ten music pieces (motifs) were prepared for the tests so that the effects of different effective duration on the temporal factors could be investigated (Table 1). The duration of each piece was about 6 s. The values of $(\tau_e)_{min}$ for the ten music pieces were calculated with the recommended integration intervals obtained using Equation [1].

For the analysis of the τ_e of each music piece, only a direct sound was radiated from the frontal-single loudspeaker in the test room. Its A-weighted sound pressure level in the center of the room was 80 dBA. A sound signal from a 1.2-m-high condenser microphone in the center of the room was used to calculate each τ_e value.

Table 1. Music pieces used. Motifs A-J are arranged in an ascending order of $(\tau_e)_{min}$ values.

Motif	Title	Composer	Measured $(\tau_e)_{min}$ [ms]	Calculated $[\Delta t_1]_p$ [ms]
A	Violin, Solo [1)]		19	8
B	Trumpet, Solo [2)]		20	8
C	Cello, Solo [1)]		25	10
D	Marriage of Figaro Overture [1)]	W. A. Mozart	30	12
E	Water Music' Suite IV [1)]	G. F. Handel	33	13
F	Sinfonietta, Opus 48, IV [3)]	M. Arnold	34	14
G	Clarinet, Solo [2)]		49	19
H	Flute, Classical Mood [1)]		65	26
I	Royal Pavane [3)]	O. Gibbons	127	50
J	Piano, Classical Mood [2)]		187	74

1) Denon, ìAnechoic Orchestral Music Recordingî; 2) Japan Audio Society, ìImpact 2 (CD-3)î; 3) The original source was made by Gottingen University (Germany)

Table 2. Number of subjects in each item of questionnaire.

Items		Motief										Total
		A	B	C	D	E	F	G	H	I	J	
	$(\tau_e)_{min}$	19	20	25	30	33	34	49	65	127	187	
Gender	Male	11	18	46	19	19	32	34	26	16	12	**233**
	Female	14	24	35	15	14	15	15	18	8	17	**175**
Age	Under 20	4	12	16	7	0	2	2	10	9	15	**77**
	20s	16	27	55	16	29	41	47	24	9	14	**278**
	Over 20	4	3	9	11	4	4	0	5	2	0	**42**
Musical experience	Yes	14	31	53	21	24	32	19	27	16	25	**262**
	No	10	11	26	13	9	15	29	16	4	4	**137**
Starting age of musical activity	Under 10	0	9	16	8	9	14	0	6	1	7	**70**
	Over 10	0	7	23	10	13	16	0	7	4	3	**83**
Term of musical activity	Under 10	9	5	12	2	6	3	10	9	0	4	**60**
	Over 10	6	7	14	7	9	9	10	11	0	6	**79**
Musical activity at present	Yes	8	21	31	16	13	22	6	14	16	18	**165**
	No	0	7	12	4	9	8	0	10	0	7	**57**
Total		**25**	**42**	**81**	**34**	**33**	**47**	**49**	**44**	**24**	**29**	**408**

3.4. Questionnaire

Before each preference test, all subjects were give questionnaires asking about musical experiences as well as gender, age, and various life styles. Part of the questionnaire contents were changed each year, and the number of subjects responding to in each item is listed in Table 2.

3.5. Preference Tests

Preference tests were conducted by using a paired-comparison method. Subjects were required to report their preference by selecting one of two sound fields. Thirty-three pairs of sound fields were judged by each subject (Table 3). Each sound field had different values of four parameters (LL, Δt_1, T_{sub}, and IACC), the values of which are listed in Table 3. As the initial setting of the system could not be changed, values

Table 3. Values of factors for each music piece.

		Sound field				
		1	2	3	4	5
LL	[dBA]	70	75	80	85	90
Δt_1	[ms]	τ_p / 4	τ_p / 2	τ_p	2 τ_p	4 τ_p
T_{sub}	[s]	$\{23(\tau_e)_{min}\}$ / 4	$\{23(\tau_e)_{min}\}$ / 2	$23(\tau_e)_{min}$	$2\{23(\tau_e)_{min}\}$	$4\{23(\tau_e)_{min}\}$
IACC		0.4	0.75	1	---	---

$\tau_p = (1 - \log_{10}A)(\tau_e)_{min}$; $A = 4.0$

of $(\tau_e)_{min}$ were not applied for temporal factors in some cases. This, however, did not affect the preference results. The interval between two sound fields (each lasting 6 s) was 2 s, and that between pairs for the preference judgment was 4 s. The music pieces used for the tests were selected by the investigator whenever the subject made no request. In almost all cases, tests were performed with a music piece selected by an investigator. In the test room, a maximum of four subjects can be tested at the same time.

After each preference test, the most preferred values of x_i and the weighting coefficients α_i for the four orthogonal factors were calculated automatically by the system. A preference curve for each orthogonal factor was obtained from a regression curve of these scale values in order to calculate most preferred values and weighting coefficients. An approximate method used to determine the most preferred values and weighting coefficients is explained briefly in Appendix B.

4. RESULTS

4.1. Temporal Factors (Δt_1 and T_{sub})

Because the most preferred values of temporal factors depended on the music piece, results obtained with each music piece have to be shown here. Figure 3 shows the cumulative frequencies of preferred Δt_1 and Tsub for each music piece. Longer preferred Δt_1 and T_{sub} were obtained from music pieces with longer $(\tau_e)_{min}$ values (Motifs H, I, and J), and shorter Δt_1 and T_{sub} were obtained from music pieces with shorter ones (Motifs A, B, C, E). This implies a relationship between the preferred temporal factors and the $(\tau_e)_{min}$ values. In terms of values at 50% of cumulative frequency, the maximum $[\Delta t_1]_p$ was for Motif I (59 ms), and the minimum $[\Delta t_1]_p$ was for Motif C (3 ms). The maximum $[T_{sub}]_p$ was obtained for Motif H and was 6.9 s, while the minimum value was obtained for Motif C and was 0.3 s. Irregular distribution was observed for Motif I of $[T_{sub}]_p$ around 6.0 s, but this discontinuous distribution may be anomalous because no other distributions with such discontinuity were obtained.

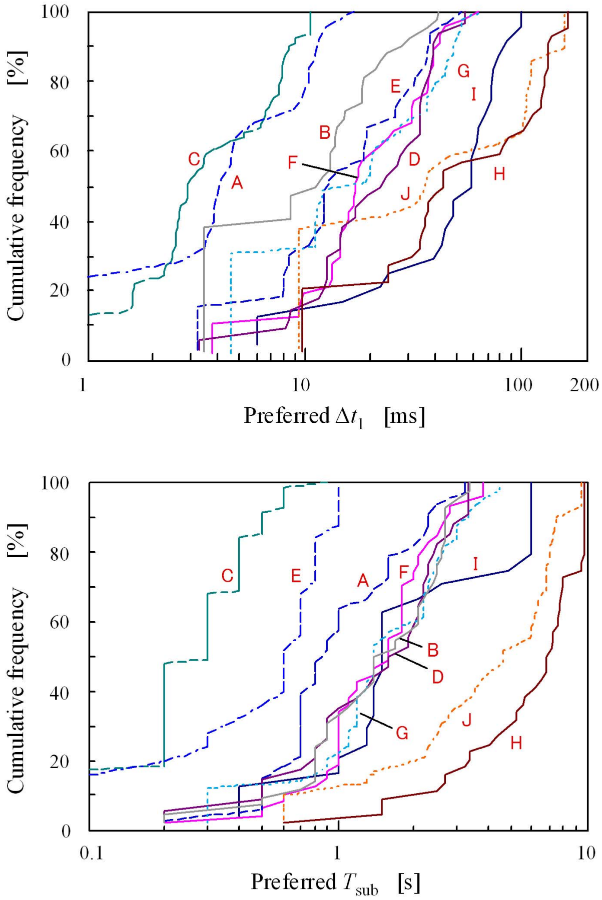

Fig. 3. Cumulative frequencies of preferred Δt_1 and T_{sub} for each music piece.

Figure 4 shows, for each music piece, the relationships between the 50% values and the most-preferred values for both temporal factors. This linear relationship clearly explains the validity of Equations [2] and [3], which predict the most preferred values of temporal factors.

To find out whether or not the distribution ranges of individual differences vary among the different pieces, we calculated the standard deviations of preferred temporal factors x_2 and x_3. The standard deviations of x_2 were small and less than 0.50 for all music pieces, and those of x_3 were also small and less than 0.39. No significant difference between these stan-

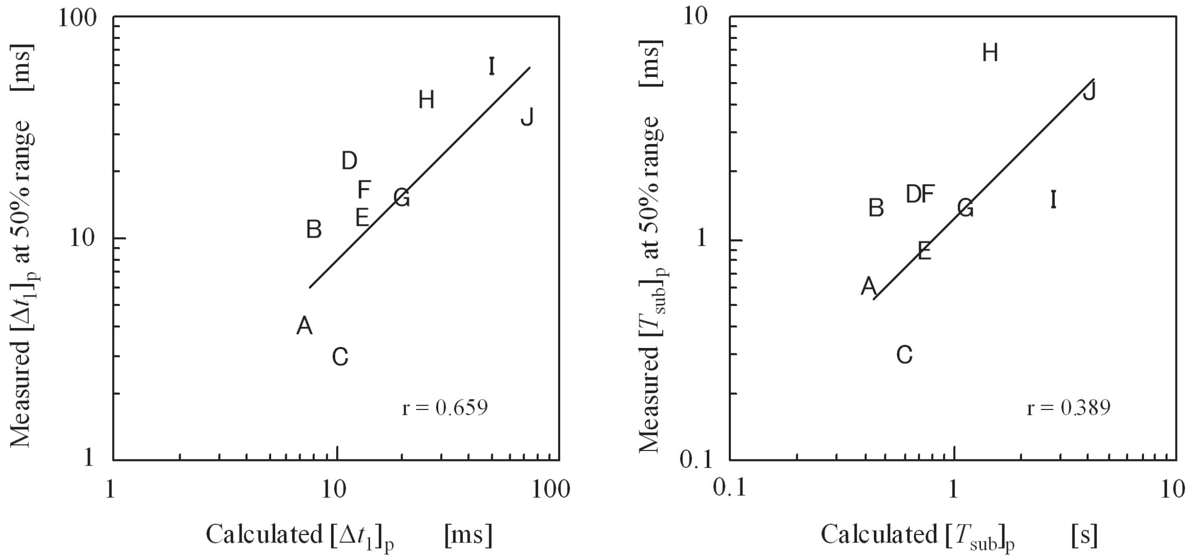

Fig. 4. Relationships between 50% values of cumulative frequencies and $(\tau_e)_{min}$ of each music piece for both temporal factors Δt_1 and T_{sub}. The inset r values are correlation coefficients.

dard deviations and $(\tau_e)_{min}$ was observed.

Figure 5 shows the distributions of α_2 and α_3. Both α_2 and α_3 were widely distributed in the range between 0 and 2. There is no specific difference among music pieces. Thus, the distributions of α_2 and α_3 also show large individual differences as well as preferred values of Δt_1 and T_{sub}.

Preferred values of temporal factors for each music piece were compared the responses to each item on the questionnaires. Analysis of variance (ANOVA) results provided information about whether or not each item is or is not a significant factor. Significant differences are indicated in Table 4 by p-values ($p < 0.05$ or $p < 0.01$) for the results if an item is one of the significant factors for individual differences. The ANOVA results revealed significant differences for several items.

We can see from the results listed in Table 4 that neither gender nor age affect individual differences. A result shows a significant difference according to age for Motif F, but it is not reliable because the number of samples is small (only 2 samples for ìunder 20î and 4 samples for ìover 30î). For Motifs B, C, H, and J with sufficient samples, there are no differences for age. Thus, it can be said that these items (gender and age) are minor factors affecting individual differences in preferred Δt_1. No other items related to the habits of the subjects (for example, whether they usually listened to music reproduced by loudspeakers or headphones, whether they were smokers or nonsmokers, whether they had consumed alcohol the night before) show significant differences.

Several items related to musical aspects show significant

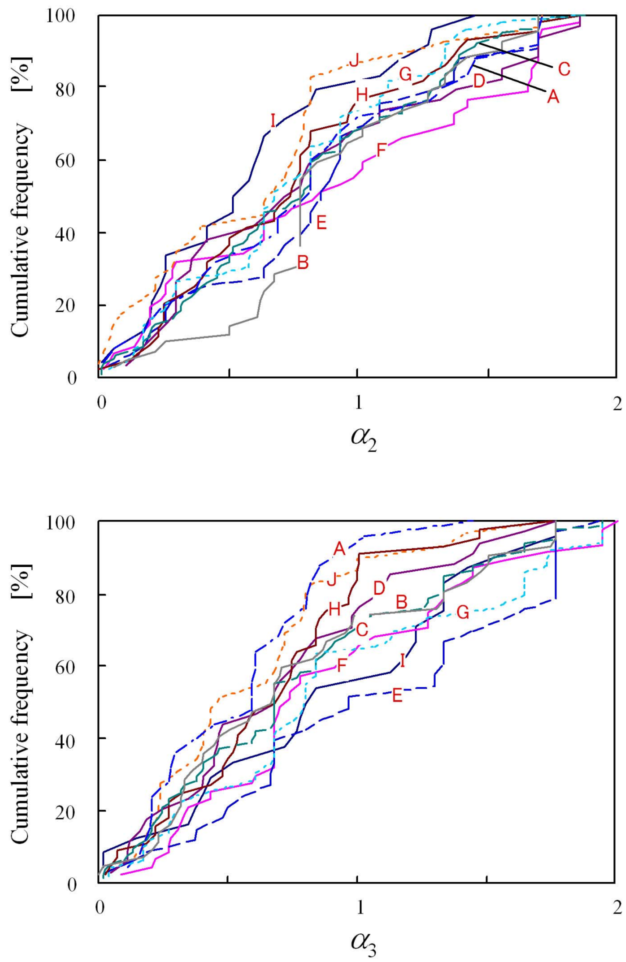

Fig. 5. Cumulative frequencies of α_2 and α_3 for each music piece.

Table 4. Results of analysis of variance (ANOVA) for preferred Δt_1

Items	Motif										
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**All**
$(\tau_e)_{min}$	**19**	**20**	**25**	**30**	**33**	**34**	**49**	**65**	**127**	**187**	
Gender (male vs. Female)	0.928	0.203	0.821	0.487	0.298	0.600	0.432	0.074	0.620	0.661	0.187
Age											
(Under 20 vs. 20s)	0.999	0.135	0.344	0.412	---	0.006**	0.623	0.154	0.746	0.752	0.011*
(Under 20 vs. Over 30)	0.269	0.903	0.999	0.929	---	0.010**	---	0.119	0.594	---	0.736
(ins vs. Over 30)	0.150	0.459	0.437	0.366	0.474	0.026	---	0.430	0.415	---	0.104
Musical experience (Yes vs. No)	0.757	0.227	0.034	0.073	0.749	0.560	0.004**	0.007**	0.733	0.836	0.021*
Starting age of musical activity (Under 10 vs. Over 10)	---	0.638	0.807	0.051	0.675	0.720	---	0.547	0.013*	0.894	0.158
Term of musical activity (Under 10 vs. Over 10)	0.719	0.890	0.006**	0.001**	0.634	0.232	0.244	0.072*	---	0.761	0.072
Musical activity at present (Yes vs. No)	---	0.297	0.005**	0.751	0.675	0.960	---	0.972	---	0.439	0.378

*: $p < 0.05$; **: $p < 0.01$

differences for preferred Δt_1. Significant differences associated with musical experience, for example, were observed for Motifs G and H. ìMusical experienceî in this context means the subjectís experience with musical activities (such as playing an instrument or singing in a chorus) in anything other than a music class in school.

Figure 6 shows the cumulative frequencies of x_2 and x_3 for subjects with and without musical experience. Comparing the responses to all music pieces, we found that subjects who had experience with musical activities had smaller values of x_2 and x_3 (that is, shorter $[\Delta t_1]_p$ and $[T_{sub}]_p$) than did subjects who had no experience with musical activities.

This tendency of smaller $[\Delta t_1]_p$ and $[T_{sub}]_p$ for experienced subjects is also evident in the results for each music piece. Smaller values of preferred $[\Delta t_1]_p$ were observed for all motifs except A, E, and I, and smaller values of preferred Tsub were observed for all motifs except H and I. This tendency was especially prominent for music pieces with solo instruments. For example, the differences in preferred x_2 (Δt_1) between subjects with and without experience were 0.35 (11 ms) for Motif G and 0.26 (23 ms) for Motif H. For x_3, the differences were 0.34 (1.1 s) for Motif B, and 0.30 (0.8 s) for Motif E.

Figure 7 clearly shows the differences of x_2 and x_3 between experienced and inexperienced subjects for each music piece.

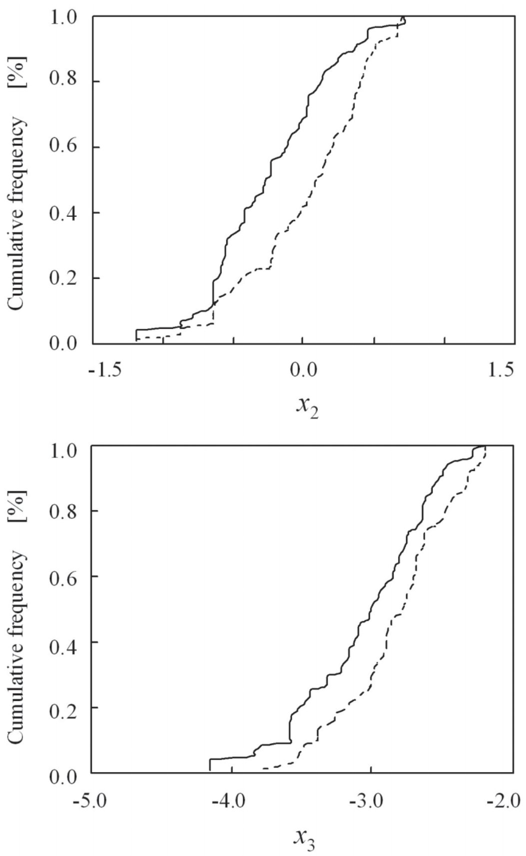

Fig. 6. Cumulative frequencies of x_2 and x_3 for subjects with (——) and without (- - -) musical experience. Values of preferred x_2 and x_3 are calculated by Equations (A4) and (A5).

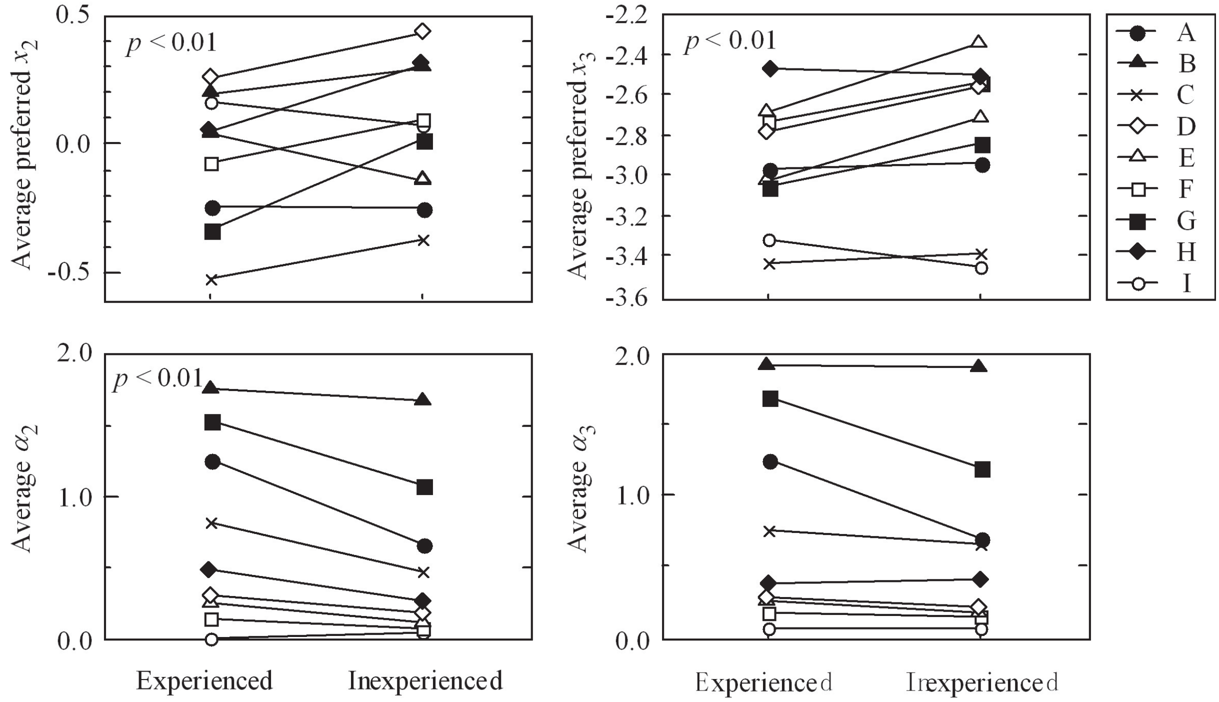

Fig. 7. Average values of preferred x_2, x_3, α_2, and α_2 for musically experienced and inexperienced subjects for each music piece.

Table 5. Number of subjects in Groups I-III in relation to absolute pitch sensation.

Group	Musical experience	Absolute pitch	Number of subjects
I	*Y*	*Y*	33
II	*Y*	*N*	61
III	*N*	*N*	44

Y and *N* indicate yes and no, respectively.

The average value of the subjective preference weighting coefficient α_2 was larger for experienced subjects (0.82) than for inexperienced subjects (0.76). As shown in Fig. 7, from each music motif the α_2 of experienced subjects differs significantly from the α_2 of inexperienced subjects ($p < 0.01$). Significant differences were not observed for α_3.

The test results obtained from subjects with absolute pitch, which is thought to be a specific ability for listening to sound, were abstracted from questionnaires and evaluated separately. As the number of samples was small, difference of x_2 and x_3 were normalized by $(\tau_e)_{min}$ for comparison. Table 5 shows how the subjects were separated in three groups: subjects who have absolute pitch and musical experience (Group I), subjects who have musical experience but do not have absolute pitch (Group II), and subjects who have neither absolute pitch nor musical experience.

Figure 8 shows the results. The average x_2 values were -0.217 for Group I, -0.042 for Group II, and 0.046 for Group III. Thus, Groups I and II including subjects with musical experience preferred sound fields with shorter Δt_1. Moreover, the subjects with absolute pitch (Group I) preferred a shorter Δt_1 than did those without absolute pitch (Group II). Table 6 shows the results of ANOVA. Significant difference was observed between the x_2 values of Groups I and III ($p < 0.05$). This result indicates that subjects who have absolute pitch as well as musical experience prefer a shorter Δt_1.

The values of α_2 for Groups I, II, and III were respectively 1.055, 0.791, and 0.700. This indicates that the degree of preference for the most preferred sound field is larger for Group I (with absolute pitch) than for Groups II and III (without absolute pitch). Significant differences were found between Groups I and III ($p < 0.05$) and between Groups I and III ($p < 0.01$).

The average values of x_3 for Groups I, II, and III were respectively -2.632, -2.537, and -2.588. No significant differences were found for this parameter. The tendency of the average values of α_3 was the same as that for the average values of α_3 (Group I > II > III), but significant differences were found between Groups I and III ($p < 0.05$) and between Groups I and III ($p < 0.05$).

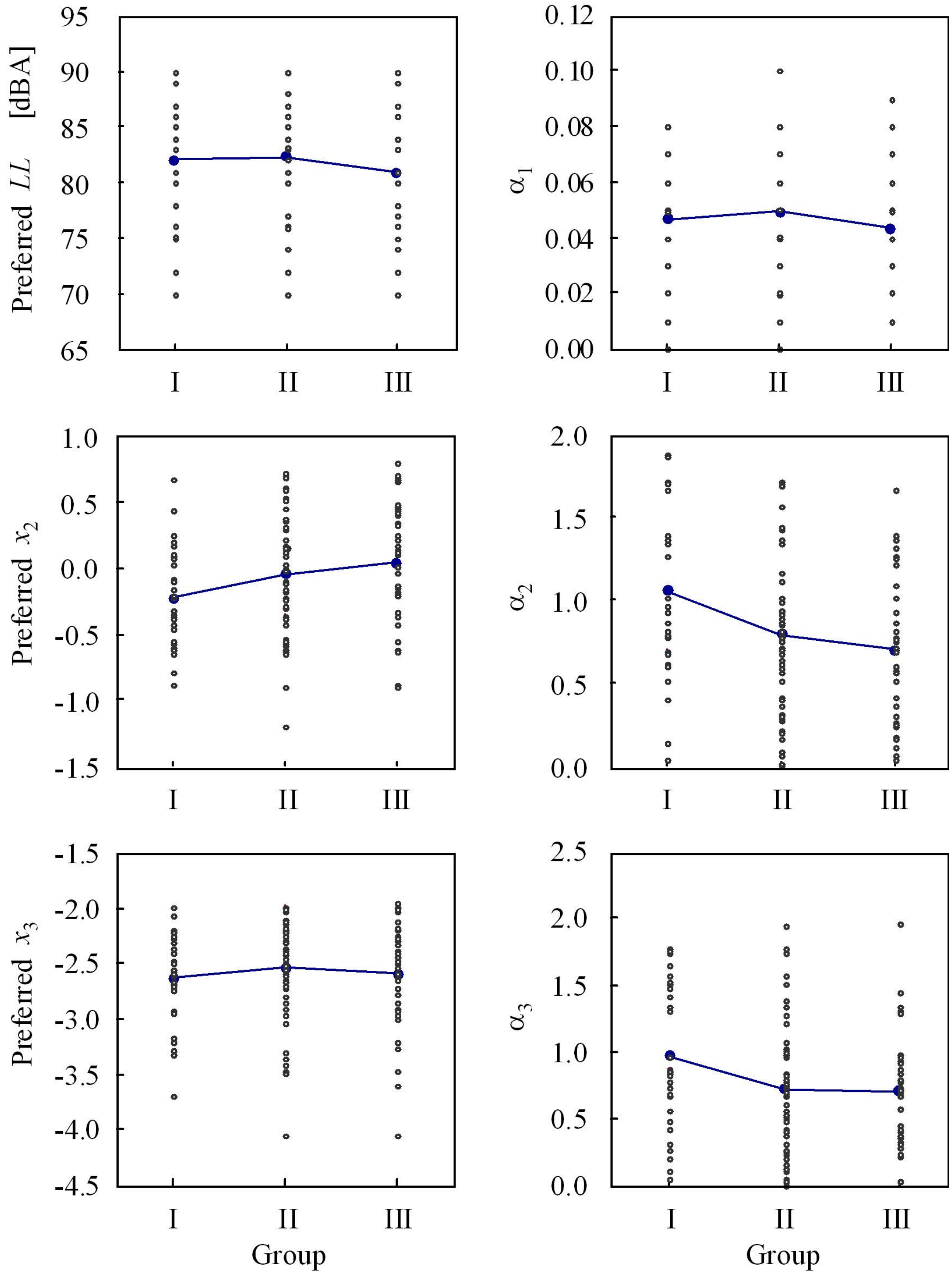

Fig. 8. Relation between absolute pitch and the average values of preferred temporal factors (x_2, x_3, α_2, and α_3) and preferred *LL* for Groups I-III.

Table 6. Results of analysis of variance (ANOVA)

	$[LL]_p$	Preferred x_2	Preferred x_3	α_1	α_2	α_3	α_4
I vs. II	0.745	0.071	0.306	0.610	0.012*	0.017*	0.397
I vs. III	0.356	0.011*	0.655	0.507	0.002**	0.018*	0.634
II vs. III	0.153	0.318	0.548	0.185	0.333	0.875	0.711
I vs. II vs. III	0.349	0.038*	0.576	0.414	0.005**	0.030*	0.697

*: $p < 0.05$; **: $p < 0.01$

4.2. Spatial Factors (*LL* and IACC)

The average value of $[LL]_p$ for all preference tests (408 cases) was 79.6 ± 5.5 dBA (mean ± sd), and this relatively small standard deviation shows that the differences in $[LL]_p$ were smaller than the differences in the temporal factors. No relationship was obtained between the values of $(\tau_e)_{min}$ and $[LL]_p$ for each music motif (correlation coefficient: r = 0.167).

For all music pieces except Motif H, the $[LL]_p$ value for subjects with experience was larger than that for subjects without experience. The largest difference was 3.5 dBA for Motif D. Values of $[LL]_p$ were almost the same for all of the groups classified according to the presence or absence of absolute pitch. It was largest for Group II (82.3 dB), smallest for Group III (80.9 dBA), and intermediate for Group I (81.9 dBA). With or without absolute pitch, there was no significant difference between the $[LL]_p$ values for subjects with and without experience.

The α_1 value for subjects without experience (0.0519) was larger than that for subjects with experience (0.0458), but the difference was significant only for Motif G (p = 0.041).

All subjects, without exception, preferred a smaller IACC. As with the listening level, for six music pieces (A-C and E-G), the average value of α_4 for subjects without experience subjects (2.20) was larger than that for subjects with experience (2.02). Although the difference was significant only for Motif B (p = 0.022), this is not reliable because of the small number of samples.

The individual differences for spatial factors thus were smaller than those for temporal factors.

5. DISCUSSION AND REMARKS

A reflection arriving within 20 ms of the direct sound has a possibility of giving coloration [10], and there were some subjects who for some music pieces preferred a first reflection arriving within a shorter Δt_1. The $[\Delta t_1]_p$ values at 50% for Motifs A and C, music pieces with shorter $(\tau_e)_{min}$, were respectively 3 and 4 ms (Fig. 3). The values of $[\Delta t_1]_p$ for Motifs A and B had a lower limit at several milliseconds. This means that a sound field with a reflection is preferred over one without a reflection. This result is in agreement with previous results (Fig. 9.22 in Ref. [3]). As such a reflection (*i.e.*, one with a quite short delay time) reinforces the loudness of a direct sound, subjects might prefer sound fields with short reflections because these reflections help locate the source of the sound.

It is interesting that subjects with musical experience preferred a shorter Δt_1 than subjects without musical experience did. Musicians may try to find a reflection reinforcing a direct sound, since one might expect them to usually listen to such details of music. Especially for solo instruments of music pieces, musicians would like to listen to music even with details (timbre or sound quality of each instrument, manner of expression, performing method, and so on). This may be why musicians prefer a sound field with shorter delay time of a first reflection. In fact, for music pieces with longer $(\tau_e)_{min}$, the average values of the delay time most preferred by musicians were less than 50 ms.

This tendency is more obvious for musicians with absolute pitch. For some music pieces (Motifs A and C), there were subjects who preferred a delay time less than 1 ms. Such very short $[\Delta t_1]_p$ appears for solo instruments much frequently than for ensemble music. Listeners with absolute pitch, who are generally musically trained from a younger age, may tend to prefer a sound field with shorter delay time of initial reflections.

The Δt_1 values preferred by musicians did not exceed 50 ms even if their $(\tau_e)_{min}$ values were above 60 ms. This is inconsistent with a proportional relationship between $(\tau_e)_{min}$ and $[\Delta t_1]_p$, like that indicated by Equation (2). General listeners expect to hear live sound fields in a concert hall, whereas performers often listen to music in the various sound fields in smaller rehearsal rooms as well as on the stages of different halls. This may make performers expect a shorter delay time for reflections. For example, a delay time of 60 ms corresponds to a distance of about 20 m (which is the general size of a sound field on a stage). This is beyond the upper limit of delay time for subjects without musical experience.

The present finding that individual differences were not significant for spatial factors is consistent with previous studies. That is, the $[LL]_p$ values were almost constant around 79 dBA for all music pieces [2] and all subjects preferred a smaller IACC.

Experienced subjects tended to have larger $[LL]_p$ values than inexperienced subjects. We think this is because experienced subjects like musicians listen to sound with large *LL* values in performing of music. As factors other than musical experience affect individual differences, however, clear differences may not be obtained.

The α values of inexperienced subjects tended to be larger for both spatial factors. This means that inexperienced listeners have a strong degree of preference for their most preferred value. It may be said that the listening conditions preferred by musicians are wide with regard to spatial factors.

The large individual differences we found for temporal factors (Δt_1 and T_{sub}) are consistent with the results of previous preference tests.

We have found that musical experience affects subjective preferences for sound fields, especially for sounds fields whose temporal factors differ. Subjects who have musical experience prefer a shorter delay time for the first reflection than do subjects without musical experience. Similarly, musicians prefer a subsequent reverberation time shorter than that preferred by subjects without musical experience. As the number of subjects was limited for each conditon, individual difference of subjective preference is not mentioned in this investigation.

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APPENDIX A

The theory of subjective preference is briefly explained here. The number of orthogonal parameters of the sound signals at both ears is limited, so the scale value S of any one-dimensional subjective responses is given by $g(x_1, x_2, ..., x_I)$. Since the four objective factors act independently and the units of these scale values are almost constant [2], we have the following equation:

$$S = g(x_1) + g(x_2) + g(x_3) + g(x_4) = S_1 + S_2 + S_3 + S_4, \quad (A1)$$

where S_i (i = 1, 2, 3, 4) is the scale value obtained from each objective parameter.

It is convenient to assign the value zero to the most preferred conditions. Then the scale values of subjective preferences obtained in the different test series using different music pieces yield the following formula:

$$S_i \approx -\alpha_i |x_i|^{3/2}, \; i = 1, 2, 3, 4 \quad (A2)$$

The α_i is a weighting coefficient. That is, the closer α_i is to zero, the smaller the contribution of factor x_1 to the subjective preference.

The factor x_1 is given by the sound pressure level difference, measured by the A-weighted network, and is given by the following equation:

$$x_1 = 20\log P - 20\log[P]_p, \quad (A3)$$

where P and $[P]_p$ are respectively the sound pressure at a specific seat and the most preferred sound pressure at any seat position in the investigated room. The factor x_2 is the logarithm of the ratio of Δt_1 to the calculated preferred Δt_1. That is,

$$x_2 = \log(\Delta t_1 / [\Delta t_1]_p), \quad (A4)$$

where Δt_1 is the interval between the direct sound and the first maximum reflection. Like the factor x_2, the factor x_3 is also derived from the ratio of T_{sub} to its calculated preferred value:

$$x_3 = \log(T_{sub} / [T_{sub}]_p), \quad (A5)$$

where T_{sub} is the 60-dB decay time of the integrated reverberation curve after Δt_1. Thus, the scale values of preference have been formulated approximately in terms of the 3/2 power of the normalized objective parameters, expressed in the logarithm for the parameters, x_1, x_2 and x_3. The spatial binaural parameter x_4 is expressed in terms of the 3/2 power of its real values, indicating a greater contribution than those of the temporal parameters are.

$$x_4 = \text{IACC} \quad (A6)$$

The IACC is defined as the maximum absolute value of the interaural crosscorrelation function within the possible maximum interaural delay range for humans.

APPENDIX B

An approximate method for calculation of a scale value for the individual subjective responses obtained by a paired-comparison test [11] is briefly described. When Case V of Thurstone's law of comparative judgment [12] is used to calculate subjective scale values, a scale value cannot be determined from a small number of trials for each pair. This is because Thurstoneís model uses a normal ogive when the probabilities of judgments are transformed into scale values. The approximate method described here, however, enables a scale value to be obtained from even a single trial.

The approximate scale value S_i of each sound field i is given by

$$S_i \approx \frac{\sqrt{2\pi}(2T_i - N)}{2N}, \quad (B1)$$

where N is the number of sound fields (in this paper, N is always equal to 5) and where T_i is the total score of each sound field i. It is given by

$$T_i = \sum_{i=1}^{N} Y_i \tag{B2}$$

where $Y_i = 1$ corresponds to a preference for i over another sound field j, $Y_i = Y_j = 0.5$ ($i = j$) and where $Y_i = 0$ corresponds to a preference for j over i. Equation (B1) is based on Case V of Thurstone's model and uses a linear domain of normal ogive ($0.05 < p < 0.95$, p: probability of judgments) in transformation. When sound fields are carefully selected within the linear range before psychological tests, a scale value can be obtained easily.

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