On the temporal window of auditory-brain system in connection with subjective responses

毛利，公勅

(Degree)
博士（工学）
(Date of Degree)
2003-03-11
(Date of Publication)
2009-07-29
(Resource Type)
doctoral thesis
(Report Number)
乙2675
(URL)
https://hdl.handle.net/20.500.14094/D2002675

博士論文

On the temporal window of auditory-brain system in connection with subjective responses

主観的反応に関連する聴覚大脳システムの時間窓について

January 2003

Graduate School of Science and Technology
Kobe University

KIMINORI MOURI

Preface

This dissertation is submitted, for the Doctor of Philosophy degree, to Graduate School of Science and Technology, Kobe University, Japan.

This dissertation attempts to describe about human auditory temporal window for acoustical measurements, based on the model of auditory - brain system. The temporal window is examined for autocorrelation function and interaural crosscorrelation function models, respectively.

I assume responsibility for any errors which may occur in the pages which follow.

Kiminori Mouri

Acknowledgments

I take this opportunity to express my thanks to the many people who have helped me, in various ways, to attain my objective of this dissertation. I would like to express my gratitude for the considerable guidance and encouragement received from Professor Yoichi Ando, Kobe University, whose contribution to this research has been substantial.

I would like to express my thanks to Dr. Hiroyuki Sakai, Dr. Shin-ichi Sato, Dr. Kenji Fujii and Ryota Shimokura, Kobe University for their assistance and discussion on experimental works for chapters 2 and 5, and strengthening interaction. And I also wish to express the thanks to Ms. Katherin Frye for her kind advice in making English sentences and the subjects who participated in the investigations. It is pleasure to acknowledge the hospitality and encouragement of the members of Ando Laboratory, Graduate School of Science and Technology, Kobe University.

Finally, I am grateful to my wife, enable me to complete this dissertation.

Kiminori Mouri

Contents

1. Introduction

2. EEG analyses relating to subjective preference and the temporal factor, Δt1 of sound field, based on ACF system

3. Preliminary study on recommended temporal window of source signals to be analyzed, in relation to its effective duration of ACF

4. Effects of telephone ring on two mental tasks relative to an office

5. The role of the interaural cross-correlation function relating to the moving sound image for the band noise

Chapter 1

Introduction

1.1. General Preface

Sound environment is strongly influenced to human life. We enjoy excellent music as amusement while traffic noise and jet plane noise make us uncomfortable feeling and often, serious damage is occurred. It is very important for estimating effects of sound environment to realize the auditory mechanism. The auditory-brain model proposed here consists of the autocorrelation mechanism, the interaural crosscorrelation mechanism and the functional asymmetry of human cerebral hemisphere [1]. Subjective attributes for sound fields can be assessed by the orthogonal physical factors extracted from these mechanisms. Based on this model, some concert halls have been constructed already, and their sound fields are considered to be excellent. Additionally, this model gives a cue to approach the human subjective responses. The final goal of this study is to clear the brain function, and this dissertation attempts to show the temporal window which is fundamental parameter to calculate the autocorrelation and the interaural crosscorrelation mechanisms.

1.2. Previous studies of acoustical measurement

All physical factors to be evaluated are extracted from binaural impulse responses at the left and right ears, h_{jl} and h_{jr} [2]. The index j indicates the sampled elements of MLS (maximum length sequence signal), which is pseudo-random binary signal, with time interval σ ($j = 0, 1, ..., L-1$). From binaural impulse responses, following orthogonal factors (LL, $\Delta t1$, Tsub, IACC, τ_{IACC}, W_{IACC}) are extracted.

(1) LL (listening level)

The LL at listener's position is obtained relative to sound pressure of the reference position. The LL at each ear is given by the autocorrelation function $\Phi_{ll,rr}(\tau)$ at = 0 of the impulse responses $h_{jl,r}$

$$\Phi_{ll,rr} = \sum_{j=0}^{L-1} h_{jl,r}^2 \quad , \qquad (1.1)$$

The relative LL in decibel scale is defined by

$$LL = 10\log_{10}\frac{\sqrt{\Phi_{ll}(0)\Phi_{rr}(0)}}{\Phi^{(ref)}(0)} \qquad \text{if } h_{jl,r} \neq 0, \qquad (1.2)$$

where

$$\Phi^{(ref)}(0) = \sqrt{\Phi_{ll}^{(ref)}(0)\Phi_{rr}^{(ref)}(0)} \quad . \qquad (1.3)$$

Here, $\Phi^{(ref)}(0)$ is the geometrical mean of the autocorrelation functions of binaural-impulse responses at $\tau = 0$ at the reference position as indicated by Eqn.(1.3). Reference position is usually 1 m apart from a sound source.

(2) Δt_1 (initial time delay gap between the direct sound and the first reflection)

The Δt_1 is defined as an initial time delay gap between the direct sound and the first reflection with the first maximum amplitude. The Δt_1 is calculated by crosscorrelation between the direct sound and its impulse response.

(3) Tsub (subsequent reverberation time)

The value of Tsub is defined by the time interval for 60 dB attenuation for the regression line of initial decay of reverberation curve. The decay curve is obtained by squaring and integrating the impulse responses [3]. The Tsub is obtained by fitting the regression line of the curves for the initial 15 dB decay after the arrival of the direct sound.

(4) IACC

The normalized interaural crosscoorrelation function is given by

$$\phi_{lr}(j\sigma) = \frac{\Phi_{lr}(j\sigma)}{\sqrt{\Phi_{ll}(0)\Phi_{rr}(0)}} \quad , \qquad (1.4)$$

where the values of $\Phi_{ll}(0)$ and $\Phi_{rr}(0)$ represent the autocorrelation functions at $\tau = 0$ of impulse responses at both ears. The denominator means the geometrical mean of the sound energies arriving at the two ears. The $\Phi_{lr}(j\sigma)$ is the crosscorrelation function of impulse responses at both ears. The magnitude of interaural crosscorrelation function is defined by

$$IACC = |\phi_{lr}(\tau)|_{\max} \quad , \quad |\tau| \le 1 \text{ [ms]}.$$

(5) τ_{IACC}

The τ_{IACC} is determined as interaural delay, at which the IACC is determined. This factor corresponds to the horizontal sound localization.

(6) W_{IACC}

The W_{IACC} is defined by the interval of delay time at a value 10 below the orthogonalized IACC. W_{IACC} is a significant factor related to the apparent source width (ASW). It is worth noticing that this factor can be evaluated by use of IACC and W_{IACC} [4, 5].

1.3. Model of auditory-brain system

A workable model of auditory brain system, involved hemispheric specialization, is proposed by Ando, Y., as shown in Figure 1.1 [1]. In this model, a sound source p(t) is located at r_0 in a three-dimensional space and a listener sitting at r is defined by the location of the center of the head, $h_{l,r}(r \mid r_0, t)$ being the impulse responses between r_0 and the left and right ear-canal entrances. The impulse responses of the external ear canal and the born chain are $e_{l,r}(t)$ and $c_{l,r}(t)$, respectively. The velocities of the basilar membrane are expressed by $V_{l,r}(x, w)$, x being the position along the membrane.

The action potentials from the hair cells are conducted and transmitted to the cochlea nuclei, the superior olivary complex including the medial superior olive, the lateral superior olive and the trapezoid body, and to the higher level of two cerebral hemispheres. According to the tuning of a single nerve fiber, the input power density spectrum of the cochlea I(x') can roughly be mapped at a certain nerve position x' [6, 7]. This fact may be partially supported by the ABR waves (I -IV) which reflect the sound-pressure levels as a function of the horizontal angle of incidence to a listener. Such neural activities, in turn, include sufficient information to attain the ACF (autocorrelation function) at a higher level, probably near the lateral lemniscus, as indicated by $\Phi_{ll}(s)$ and $\Phi_{rr}(s)$. Also, the interaural cross-correlation mechanism may exist at the inferior colliculus. It is concluded that the output signal of the interaural cross-correlation mechanism including IACC and the loci of maxima may be dominantly connected to the right hemisphere. Therefore, human physiological and psychological attributes, relating to sound stimuli, can be described by ACF and IACF (interaural cross-correlation function).

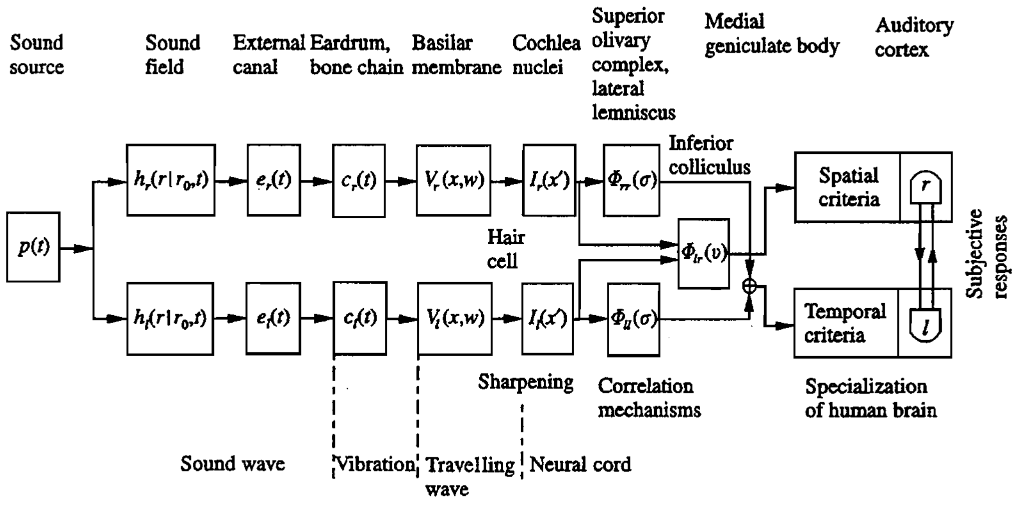

Figure 1.1 Model of auditory-brain system.

1.4. Definition of the physical factors extracted from ACF and IACF

The physical factors, $\Phi(0)$, ϕ_1,τe, and τ_1 were extracted from the ACF and IACC, τ_{IACC}, and W_{IACC} were extracted from the IACF [1, 8, 9, 10]. The definition of the ACF and the IACF are expressed as follows:

$$\Phi_p(\tau) = \frac{1}{2T}\int_{-T}^{+T} p'(t)p'(t+\tau)dt, \qquad \Phi_{lr}(\tau) = \frac{1}{2T}\int_{-T}^{+T} p'_l(t)p'_r(t+\tau)dt \quad (1.5)$$

Here p'(t) = p(t)*s(t) being the ear sensitivity. For convenience, s(t) may be chosen as the impulse response of an A-weighted network.

$\Phi_{lr}^{(n)}(\tau)$ is the IACF of the nth reflection; $\Phi_{ll}^{(n)}(0)$, and $\Phi_{rr}^{(n)}(0)$ are the respective sound energies arriving at the two ears from the nth reflection.

Four physical factors are obtained from the ACF:

(1) energy represented at the origin of the delay, $\Phi p(0)$;

(2) effective duration of the envelope of the normalized autocorrelation function, τe (which is defined by the 10-percentile delay), representing a kind of repetitive feature or reverberation containing the source signal itself;

(3, 4) fine structure, including peaks and dips with their delays: the delay time and amplitude of the first peak-namely, τ_1 and ϕ_1.

Three physical factors are obtained from the IACF:

(1) IACC is the maximum value of the IACF within the time delay of 1 ms;

(2) τ_{IACC} corresponds to the interaural time delay for the horizontal angle;

(3) W_{IACC} corresponds to the apparent source width (ASW) mainly.

The physical factors, $\Phi(0)$, ϕ_1, τ_e, and τ_1 were extracted from the ACF and IACC, τ_{IACC}, and W_{IACC} were extracted from the IACF. The definition of the ACF and the IACF are illustrated in Figure 1.2 and 1.3.

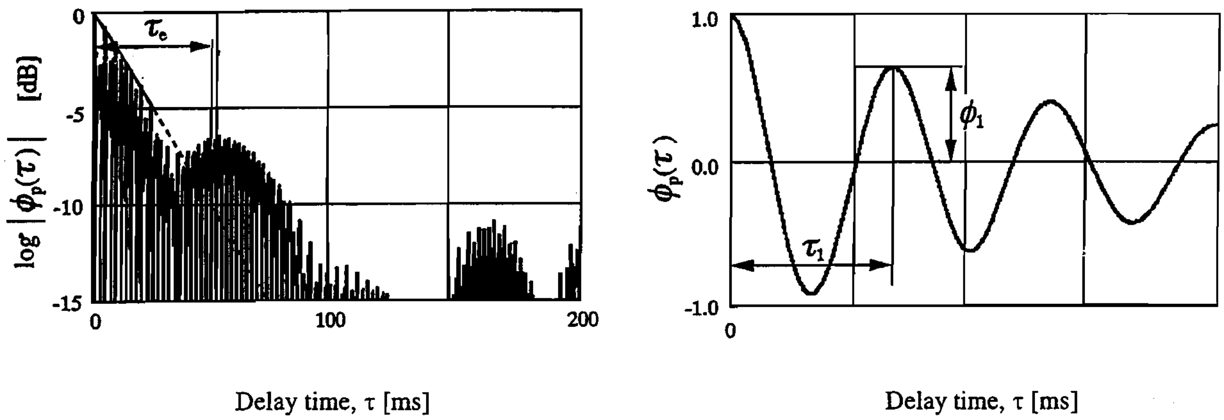

Figure 1.2 Physical factors extracted from ACF.

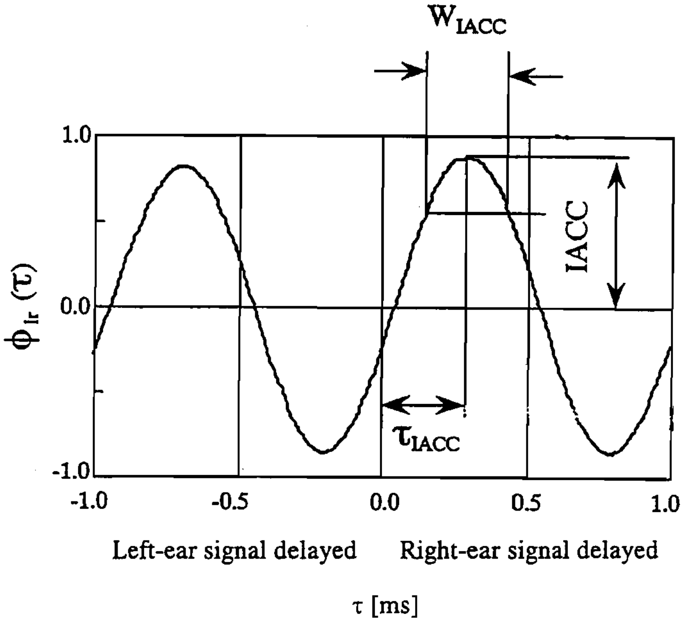

Figure 1.3 Physical factors extracted from IACF.

1.5. Aim of this study

The aim of this dissertation is to identify the temporal window of the autocorrelation and interaural crosscorrelation functions of auditory-brain system. In chapter 2, the subjective and physiological effects of sound signal are examined to show the importance of calculating physical factors extracted from autocorrelation function. In chapter 3, the temporal window of the autocorrelation function is investigated relating to physical factors. In chapter 4, the effects of sound for mental work are researched relating to the recommended temporal window. In chapter 5, the temporal window of the interaural crosscorrelation function is researched also.

Chapter 2

EEG analyses relating to subjective preference and the temporal factor, Δt_1 of sound field, based on ACF system

2.1. Introduction

A workable model of the human auditory-brain system, which incorporates hemispheric asymmetry, was proposed by Ando [1]. It contains autocorrelators and an interaural crosscorrelator for processing acoustic information [1, 2], as shown in Figure 1.1. It is found that the left cerebral hemisphere is specialized for temporal factors such as the initial time delay gap between the direct sound and the first reflection sound (Δt_1) and reverberation time (Tsub) [3, 4, 5]. The right cerebral hemisphere is associated with spatial acoustic factors: the sensation level (SL) and the magnitude of interaural crosscorrelation (IACC) [3]. Thus, hemispheric specialization is considered to be one of the most fundamental functions of the brain.

In the previous investigations, it was demonstrated that the most preferred Δt_1 is determined by the minimum value of the effective duration (τ_e)min of the source signal when the A-value is unity [6]. The value of (τ_e)min may be found in the most rapid movement of the source signal, which may be considered to be the most sensitive part for our brain. The A-value is defined as total amplitude of reflections and reverberation. The effective duration (τ_e) of ACF is obtained by the delay time such that the initial decay rate between 0 to -5 dB of the envelope of the normalized ACF extrapolated at -10 dB, as shown in Figure 1.2. To obtain the running ACF, each τe is calculated by moving part of the integration interval (2T) at the running interval (100 ms), as shown in Figure 2.1.

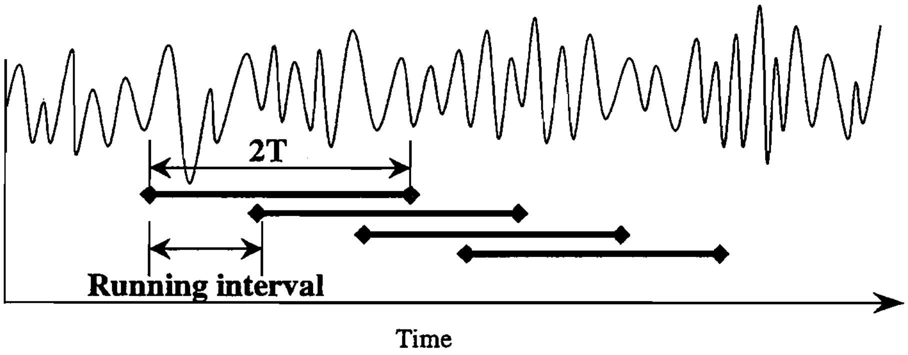

Figure 2.1 Relationship between 2T and running interval on calculating running τ_e.

The temporal window (2T) of ACF, which is considered to correspond to the psychological present [7], must be determined. The psychological present defined here is a short-time duration of stimuli needed for subjective responses. The duration in this study is defined as 2T = 2.5 s, because it is found that this value typically corresponds to the physiological response associated with subjective preference [4]. It has been discovered that the value of τ_e of alpha-brain waves from the left temporal area is related to the scale value of subjective preference in change of both Δt_1 and reverberation time [4, 5]. In this study, this method is utilized to demonstrate the hypothesis described below.

Namely, it is hypothesized that subjective preference is judged at the (τ_e)min of a source signal, so that the value of τ_e of alpha-brain waves is affected typically at that part. Since Δt_1 is considered to be processed as a temporal factor, it is assumed that a significant tendency on the left hemisphere exists.

2.2. Procedure

2.2.1. Experiment 1

The purpose of this experiment is to select the subjects whose subjective responses are associated with (τ_e)min. 14 right-handed subjects (10 males and 4 females aged 25 to 35 years old with normal hearing ability) were investigated to evaluate the subjective preference for Δt_1. As shown in Figure 2.2, the source signal was the initial 3 s of the vocal music motif S (Schubert, Die Forelle, performed by Ms. Mikiyo Setoguchi), which was recorded in an anechoic chamber. The running τe of the source signal was calculated. The value of (τ_e)min obtained is about 3 ms (2T = 2.5 s), as shown in Figure 2.3. The five sound fields where consisted of the direct sound and a single reflection with change of Δt_1: 5, 10, 20, 40 and 80 ms were prepared. Two loudspeakers were located at 1.5 m in front of the subject, and produced the direct (elevation 0 degree) and reflection sound (elevation 17 degrees) keeping IACC = 1.0. The A-value was fixed at 1, and the total sound pressure level was 80 dBA at the peak level. Paired-comparison tests were performed for all pairs of sound fields in the anechoic chamber, asking subjects to select which of two sound fields they preferred to listen to. This test was repeated ten times for each subject. The scale value (SV) of individual subjective preference was calculated by applying the law of comparative judgement (case V) [8], and was reconfirmed by the goodness of fit [9].

Results of the scale values of subjective preference are shown in Figure 2.4. The figure shows that almost subjects preferred sound fields in the range of Δt_1 less than 10 ms. It is worth noting that the most preferred calculated value of Δt_1 for A = 1.0 corresponds to the minimum value of τ_e obtained by the running ACF of the music signals used for subjective preference judgements, i.e.,

$[\Delta t_1]p$ for global subjects [6].

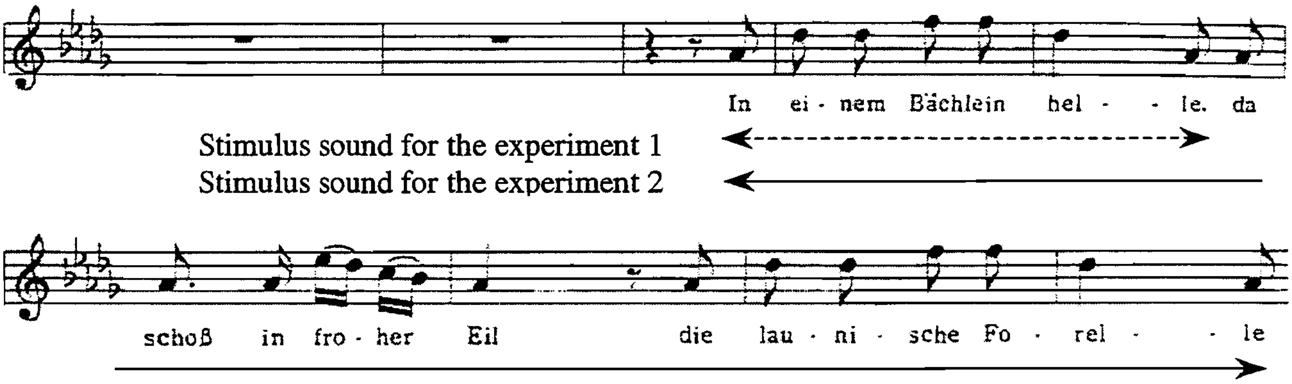

Figure 2.2 Musical score of motif S (Schubert, Die Forelle).

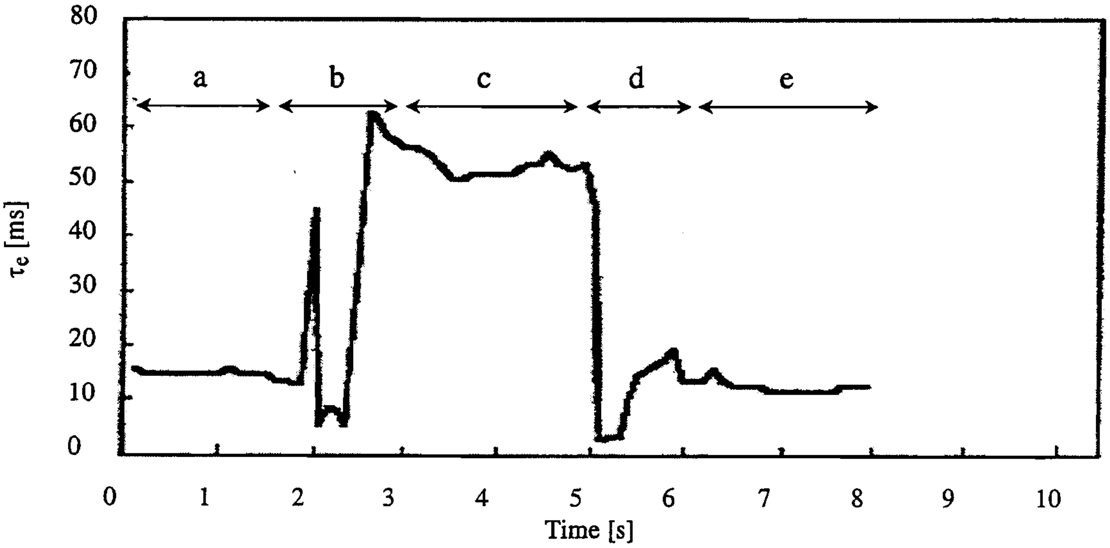

Figure 2.3 Values of τe obtained by analysis of the running ACF (2T=2.5 s with the running interval of 100 ms) of vocal music.

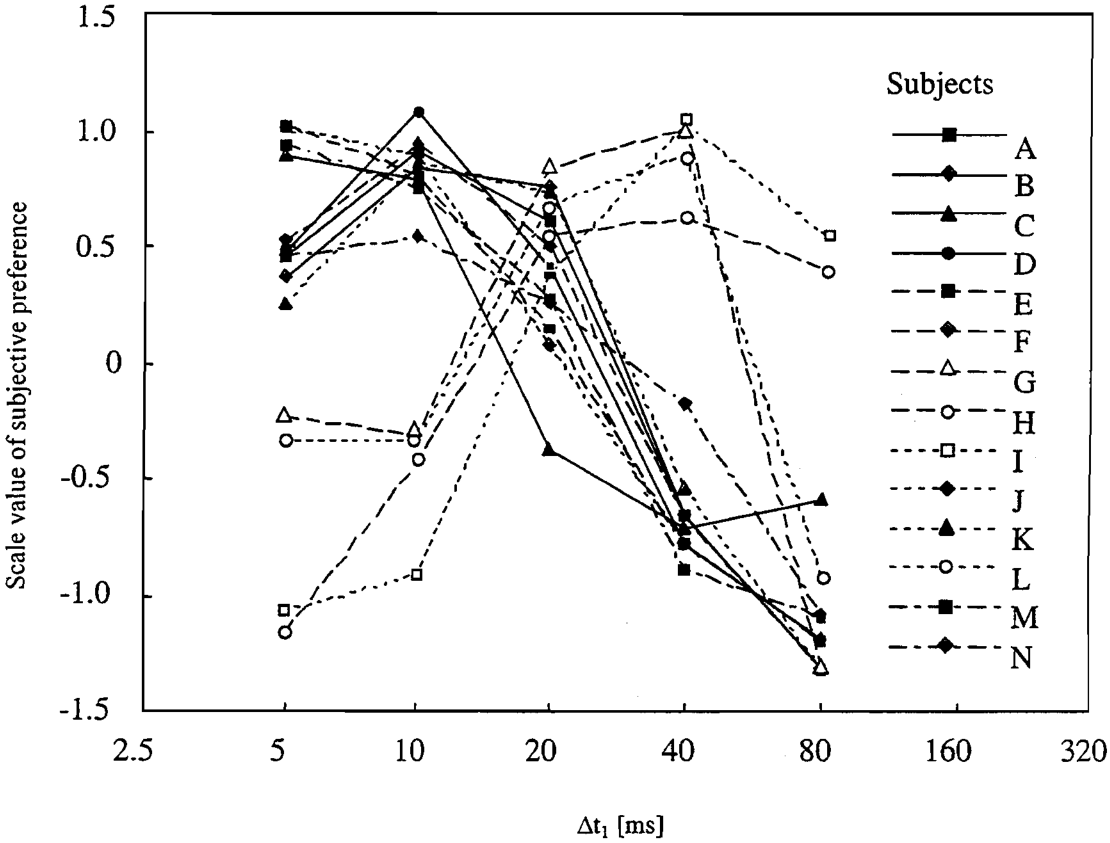

Figure 2.4 Scale values of subjective preference as a function of Δt_1 for 14 subjects.

2.2.2. Experiment 2

The ten subjects (A, B, C, D, E, F, J, K, M, N: 7 males and 3 females), were selected for the second experiment because others did not prefer the Δt_1 which is less than 10 ms. And the relationship between the running τ_e of the source signal and the τ_e of the range of alpha-brain waves for two sound fields, which was preferred and less preferred conditions of Δt_1, was investigated. Prior to this research, all subjects were instructed not to drink any alcohol and to refrain from smoking for the three days before the recording of the continuous brain wave (CBW). The block diagram of the experimental set up is shown in Figure 2.5. The source signal, which was a piece of the music motif S with the duration of 10 s (see Figure 2.2), was given at the sound pressure level of 80 dBA. According to the results of the selected ten subjects (Figure 2.4), the value of Δt_1 of the preferred sound field was selected at 10 ms, and that of the less preferred sound field was 80 ms.

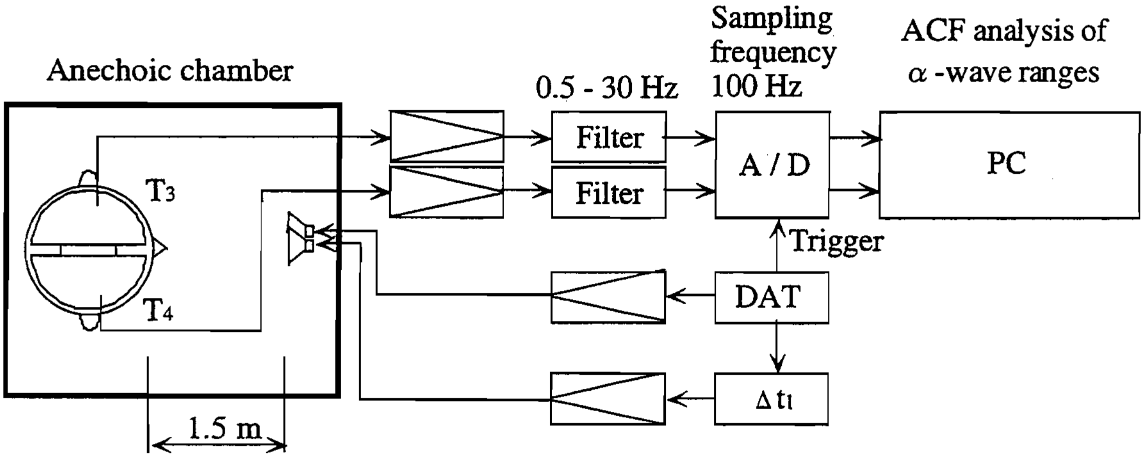

Figure 2.5 Block diagram of analyzing alpha waves from T_3 and T_4.

Each subject sat in the anechoic chamber and listened to the two sound fields alternatively. The CBWs from the left and right cerebral scalps were picked up by silver electrodes at T_3 and T_4 (International 10 / 20 Standards[10]). The reference electrodes were positioned on both the left and right earlobes. The ground electrode was placed on the forehead. The sampling rate was 100 Hz after the low-pass filter of 30 Hz simultaneously. The alpha-wave range of CBW signals was analyzed by the running ACF similar to music signals after passing through a digital band-pass filter with cut-off frequencies (140 dB/octave slopes) of 8 to 13 Hz (see Figure 2.6). The amplitude of the first-reflection sound corresponded to that of the direct sound, keeping $A = 1$.

2.3. Results and discussion

The effects of the difference of Δt_1, and the difference between the left and right hemispheres (LR) were examined for all ten subjects using the three-way ANOVA, as shown in Table 2.1. The effects of the individual differences (Subject) Δt_1 and LR are all significant ($p < 0.01$). In addition, there are significant interference effects among Subject, Δt_1 and LR ($p < 0.01$), but the interference effect between Δt_1 and LR is not significant ($p < 0.10$). As shown in Figure 2.7, it is found that the value of τ_e in the alpha-wave range for the sound field of $\Delta t_1 = 10$ ms is significantly greater than that of $\Delta t_1 = 80$ ms only in the left hemisphere (t-test: $p < 0.005$). No significant difference is found in the right hemisphere. The effects of Δt_1 and the music parts (a, b, c, d, e) were examined for T_3 and T_4, separately. As shown in Tables 2.2 and 2.3, the significant effect of Δt_1 and the interference effect between the music part and Δt_1 are obtained on the left hemisphere (T_3), but are not obtained on the right (T_4). Thus, it is reconfirmed that the left hemisphere is associated with the temporal factors of sound fields such as Δt_1. This result supports the model [1, 2], and is consistent with those of the previous investigations [4, 5]. Also, it agrees well with hemispheric specialization [3]. Hereafter, we focus on the left hemisphere.

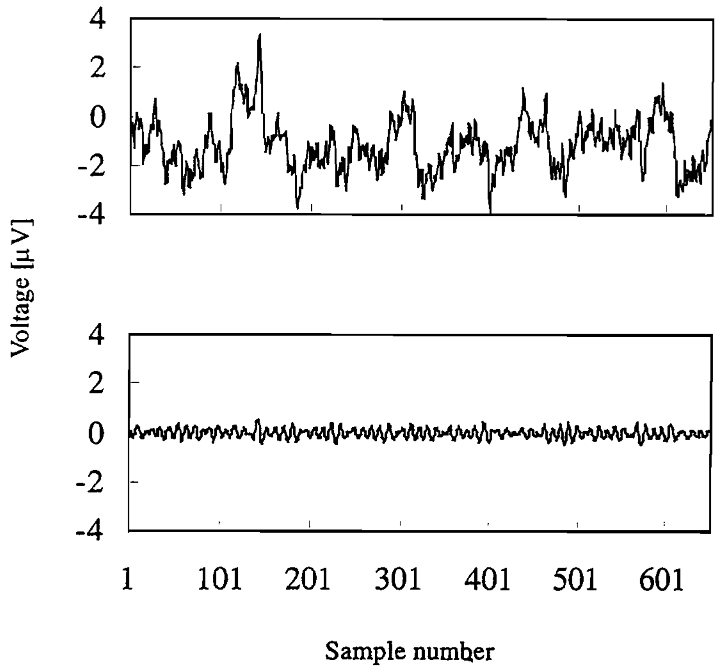

Figure 2.6 Example of brain wave (upper) and alpha-brain waves (lower).

Table 2.1 Analysis of variance for all τ_e in the alpha-brain waves

Factor	df	*F*-value	*p*
Subject	9	1062·5	$< 0·01$
Δt_1	1	9·0	$< 0·01$
Subject Δt_1	9	23·1	$< 0·01$
LR	1	314·0	$< 0·01$
Subject *LR*	9	114·2	$< 0·01$
Δt_1 *LR*	1	3·6	$< 0·10$
Subject Δt_1 *LR*	9	14·2	$< 0·01$
Error	59 700		

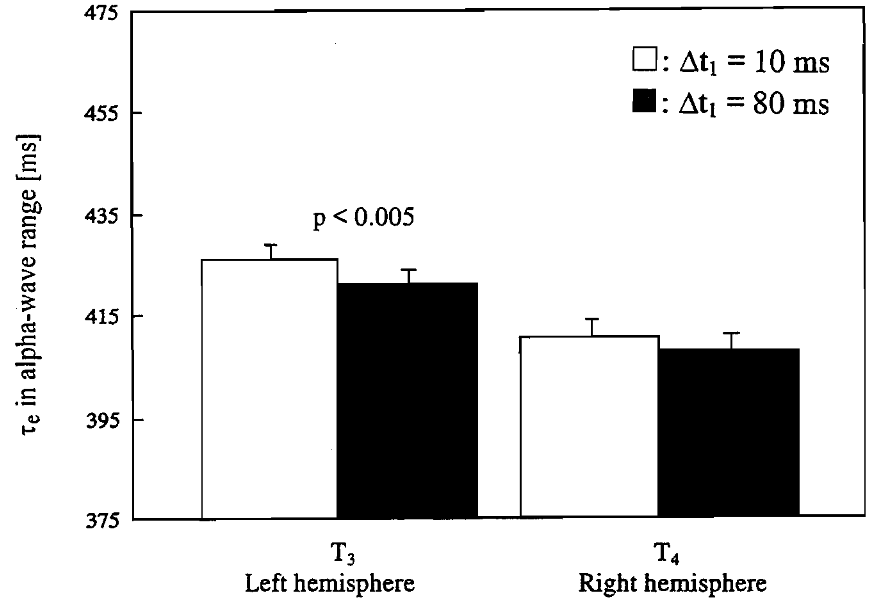

Figure 2.7 Averaged values of τ_e obtained by analysis of running ACF.

10 and 80 ms were calculated for each part (a, b, c, d, e) separately, as shown in Figure 2.8. It is remarkable that the ratio is maximum at the part of d, and this part is in accord with the (τ_e)min of the source signal, as shown in Figure 2.9.

As shown in Figure 2.8 (d), the averaged value of τ_e of the alpha-brain waves for the sound field with $\Delta t_l = 10$ ms at the part of d is significantly greater than that of $\Delta t_l = 80$ ms only in the left hemisphere (t-test: $p < 0.0001$). This result reveals that subjective preference is closely associated with the (τ_e)min of the music signal. At the part (d), this tendency is typically reconfirmed for almost all subjects (Sign test: $p < 0.05$), as shown in Figure 2.10.

Table 2.2 Analysis of variance of τ_e in the alpha-brain waves for Δt_l at T_3 with the factors: pars (a-e), Δt_l

Factor	df	F-value	p
Part	4	57·4	< 0·01
Δt_l	1	7·5	< 0·01
Part Δt_l	4	9·6	< 0·01
Error	29481		

Table 2.3 Analysis of variance of τ_e in the alpha-brain waves for Δt_l at T_4 with the factors: pars (a-e), Δt_l

Factor	df	F-value	p
Part	4	62·9	< 0·01
Δt_l	1	2·8	0·10
Part Δt_l	4	1·3	0·28
Error	30239		

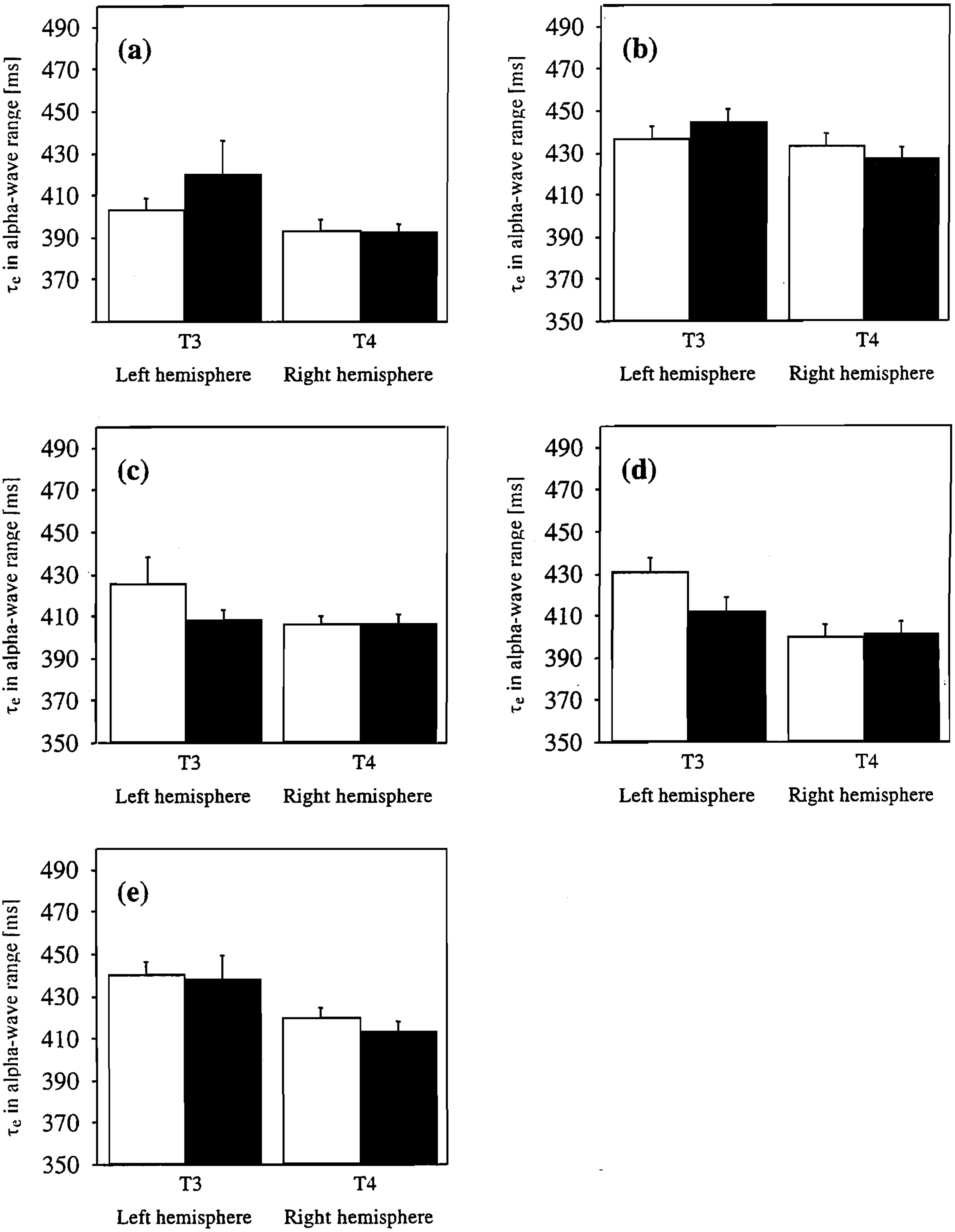

Figure 2.8 Averaged values of τ_e in the alpha-wave range from T_3 and T_4 for music piece of a to d; ☐: $\Delta t_l = 10$ ms, ■: $\Delta t_l = 80$ ms.

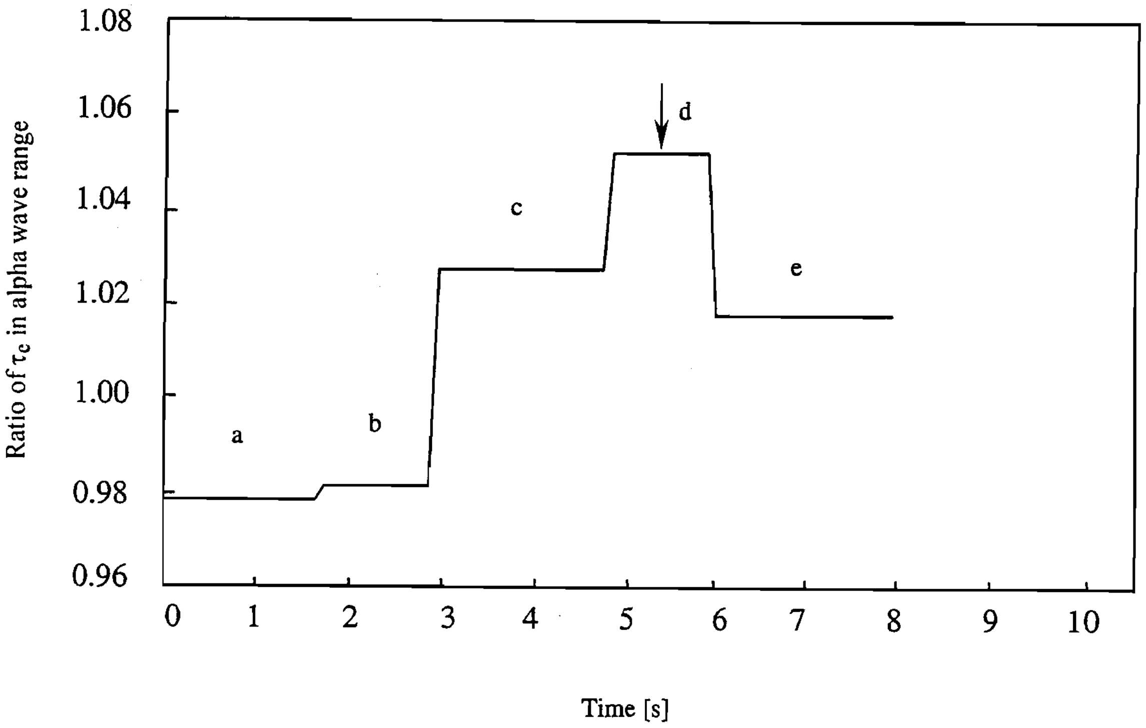

Figure 2.9 Ratios of the τ_e value in the alpha-brain wave range of all subjects tested at T_3 (left hemisphere) for the change of Δt_1 = 10 and 80 ms obtained at corresponding parts of music signals: a-e which correspond to these in Figure 2.3.

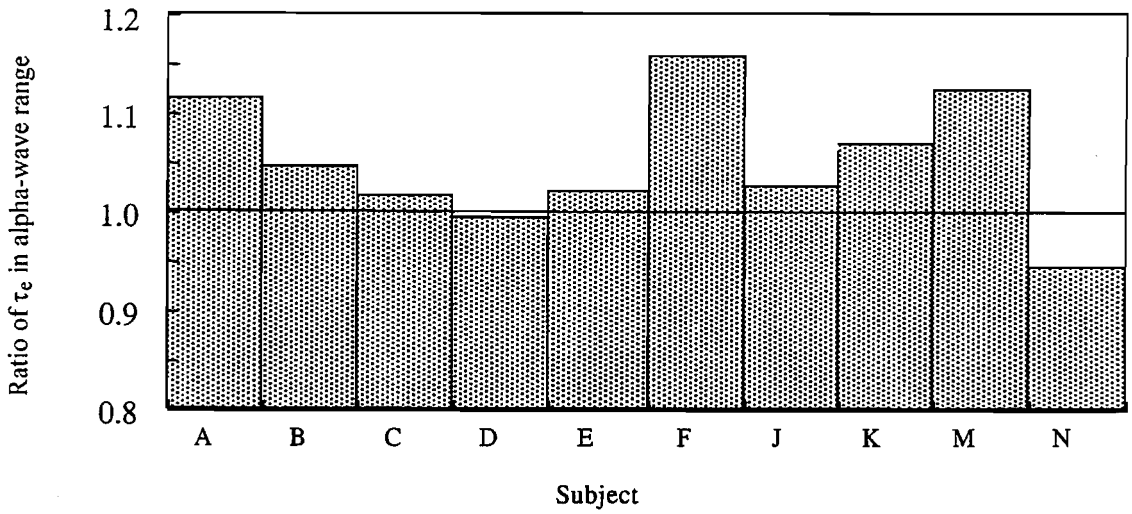

Figure 2.10 Ratio of the τ_e values in the alpha-wave range for change of Δt_1 obtained at T_3 (left hemisphere): [(τ_e value at 10 ms) / (τ_e value at 80 ms)], obtained for each individual.

2.4. Conclusions

The value of $(\tau_e)_{\min}$ of a source signal is the most important for the brain which affects subjective preference with changing temporal factor Δt_1. It is demonstrated that subjective preference judged at the $(\tau_e)_{\min}$ of a source signal is closely related to the value of τ_e of the alpha-brain waves obtained from the left hemisphere. These results mean that the human left hemisphere is sensitive to the most rapid movement of a source signal.

Chapter 3

Preliminary study on recommended temporal window of source signals to be analyzed, in relation to its effective duration of ACF

3.1. Introduction

Subjective evaluations for the environmental sound should be considered to design the sound environment for each office worker. In the concert hall acoustics, the human auditory - brain system characterized by the autocorrelation function (ACF) and the interaural cross - correlation function (IACF) and the specialization of cerebral hemispheres has been well accepted for the subjective evaluations [1, 2, 3, 4]. In order to calculate the running ACF of music and speech signal for subjective preference judgement, the integration time duration (2T) has been selected as 2.0 s. In this paper, we discuss a suitable 2T of noise and other sounds evaluating the loudness and the pitch. Such a duration of (2T) is considered as a time window of our auditory - brain system because it is regarded as minimum unit for analyzing sound sources.

The purpose of this study is to research the 2T relating to the loudness and the pitch of noise sources in an office. In this research, $\Phi(0)$ is associated with the loudness and the pitch is considered to be consisted by ϕ_1 and τ_1.

3.2. Procedure

In this research, telephone ring, the fan noise of the air conditioner, the sound of key - punch, the fan noise of the personal computer, voice, music H (Beethoven, Symphonie No. 6, F - dur, op. 68, Pastrale Andante molto mosso) and music I (Mozart, String quintets, No. 4, 1st mov.) were chosen as the sound sources. Music H has slow tempo while music I has fast tempo.

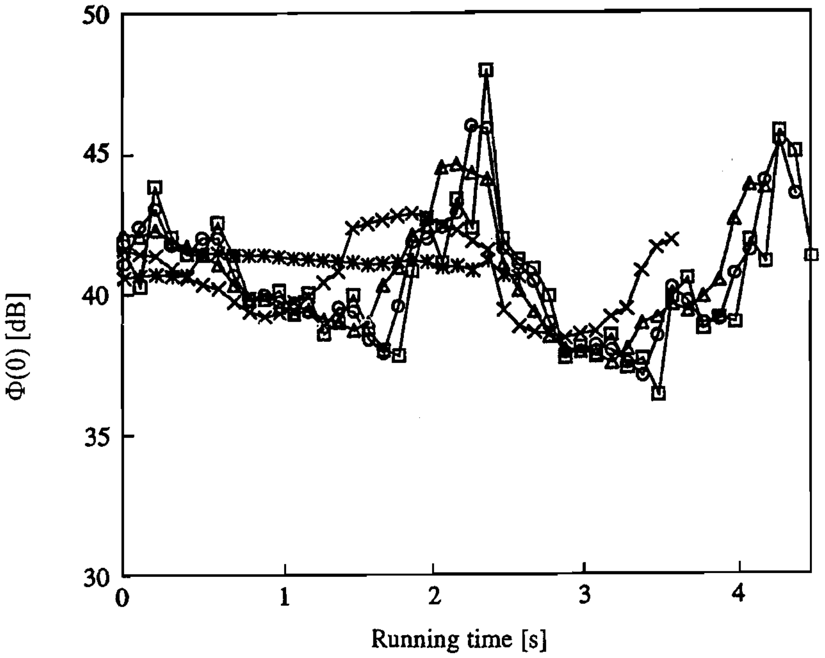

Figure 3.1 Running Φ(0) of music H (Beethoven, Symphonie No. 6, F - dur, op. 68, Pastrale Andante molto mosso) relating to 2T: □, 2T=0.1 s; ○, 2T=0.2 s; △, 2T=0.4 s; ×, 2T=1.0 s; *, 2T=2.0 s.

The running evaluated physical factors of the ACF and the IACF of music H was calculated for 2T = 0.1, 0.2, 0.4, 1.0 and 2.0 s with the running interval of 0.1 s, as shown in Figures 3.1 because the frequency information up to 10 Hz is included when 2T is up to 0.1 s.

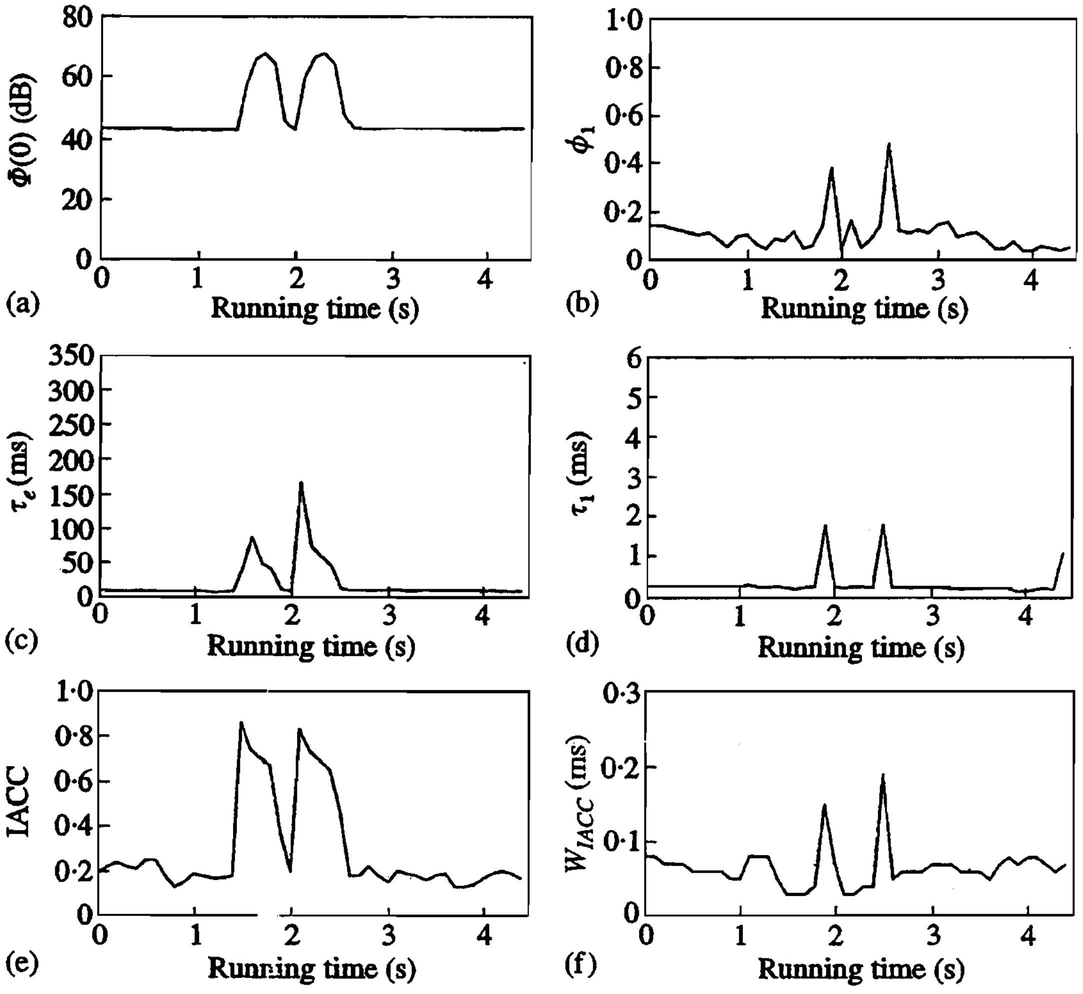

Figure 3.2 Analysis of the running ACF and the running IACF of telephone ringing with 2T=0.2 s: (a) Φ(0); (b) ϕ_1; (c) τ_e; (d) τ_1; (e) IACC; (f) W_{IACC}.

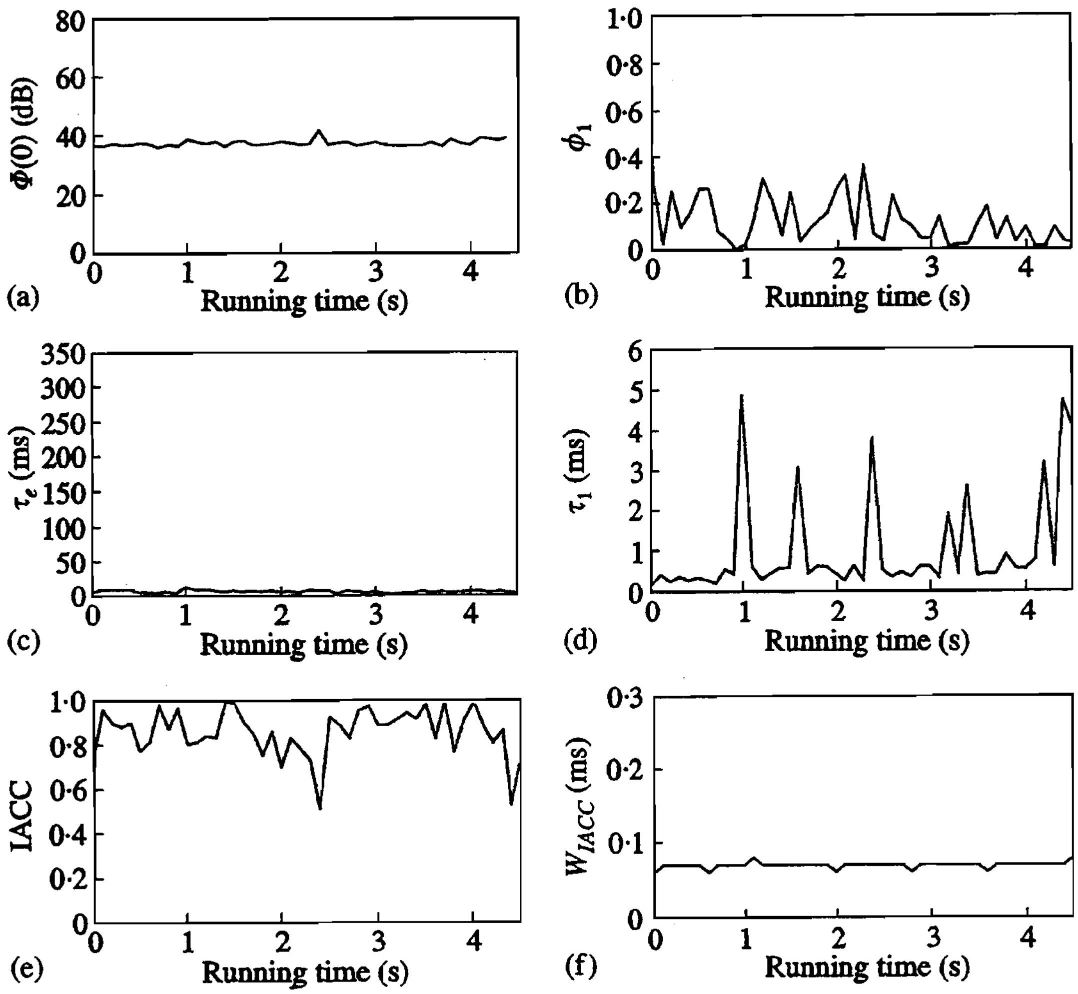

Figure 3.3 Analysis of the running ACF and the running IACF of the noise of air conditioner with 2T=0.1 s: (a) Φ(0); (b) ϕ_1; (c) τ_e; (d) τ_1; (e) IACC; (f) W_{IACC}.

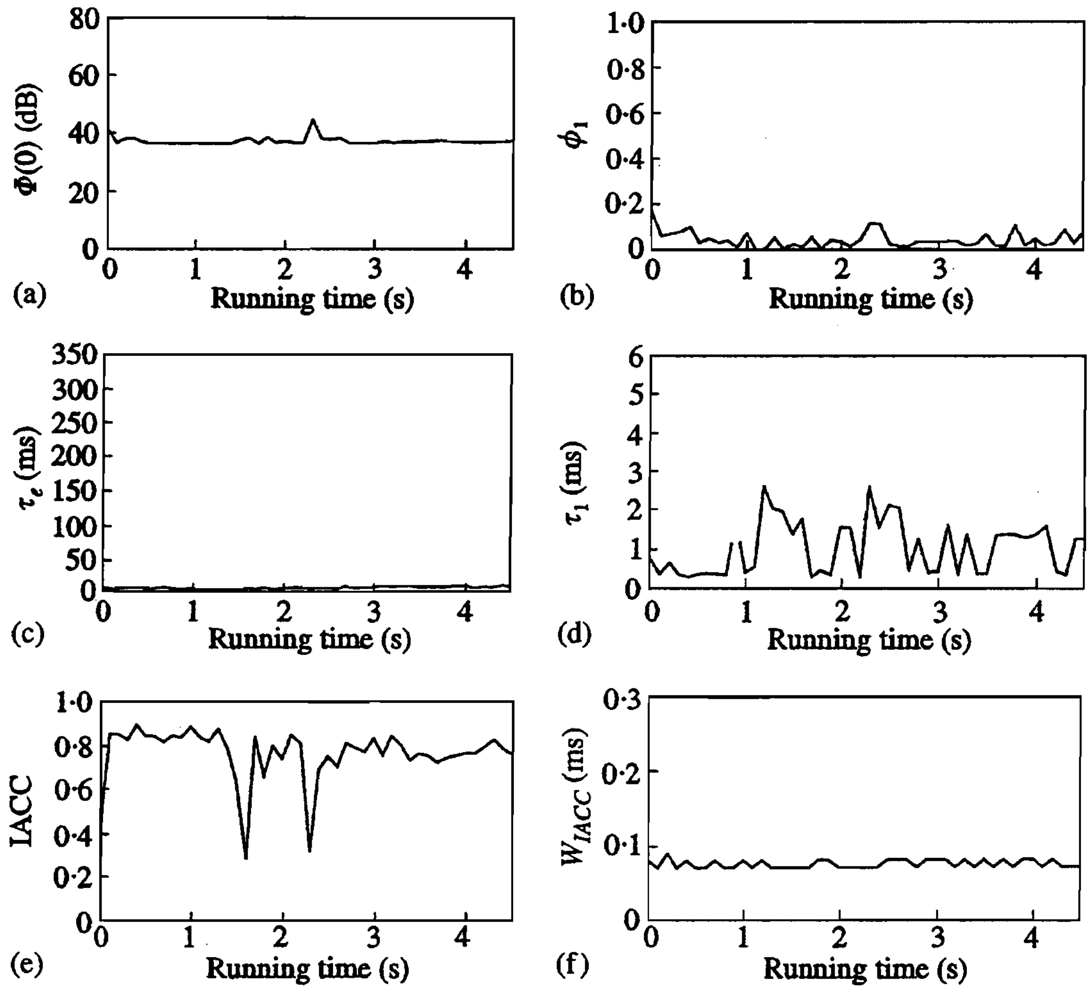

Figure 3.4 Analysis of the running ACF and the running IACF of fan noise of personal computer with 2T=0.1 s: (a) Φ(0); (b) ϕ_1; (c) τe; (d) τ_1; (e) IACC; (f) W_{IACC}.

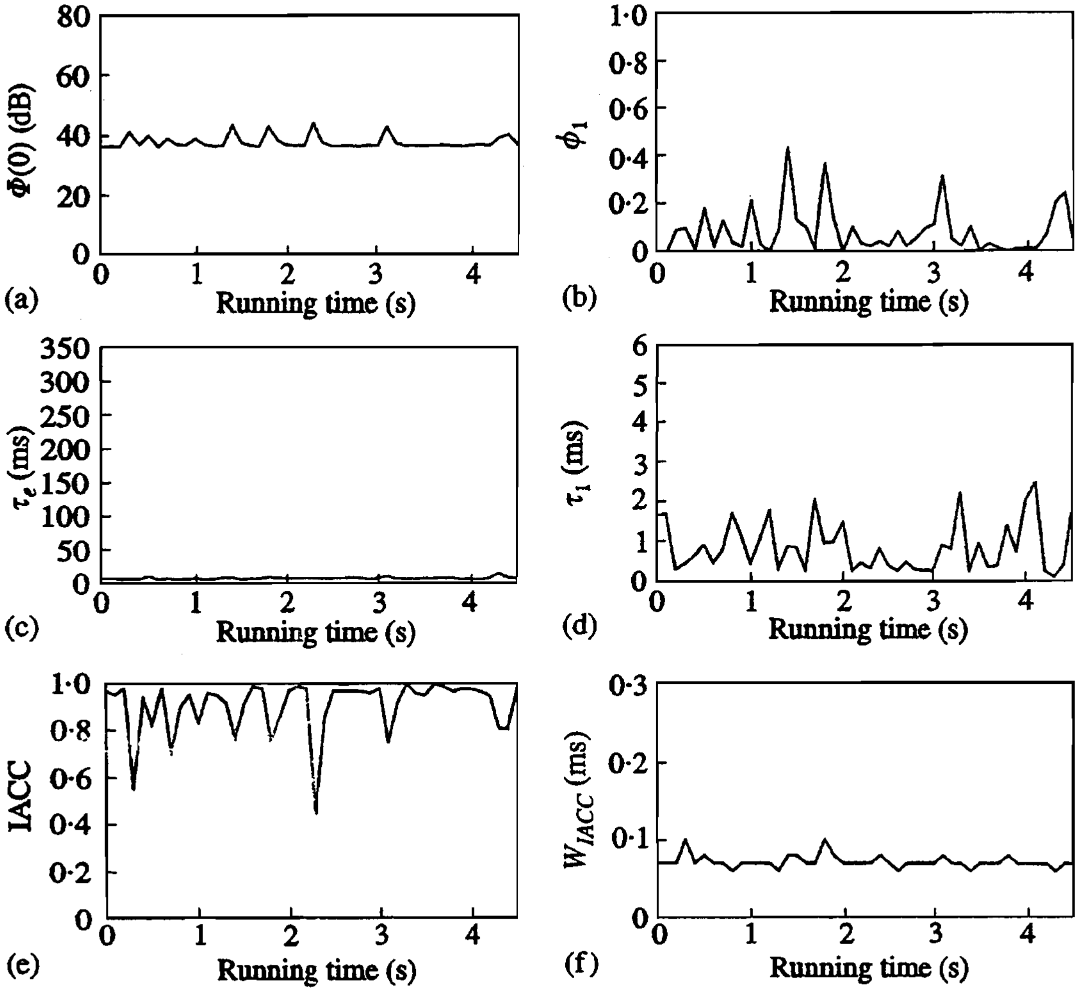

Figure 3.5 Analysis of the running ACF and the running IACF of the noise of key-punch with $2T=0.1$ s: (a) $\Phi(0)$; (b) ϕ_1; (c) τ_e; (d) τ_1; (e) IACC; (f) W_{IACC}.

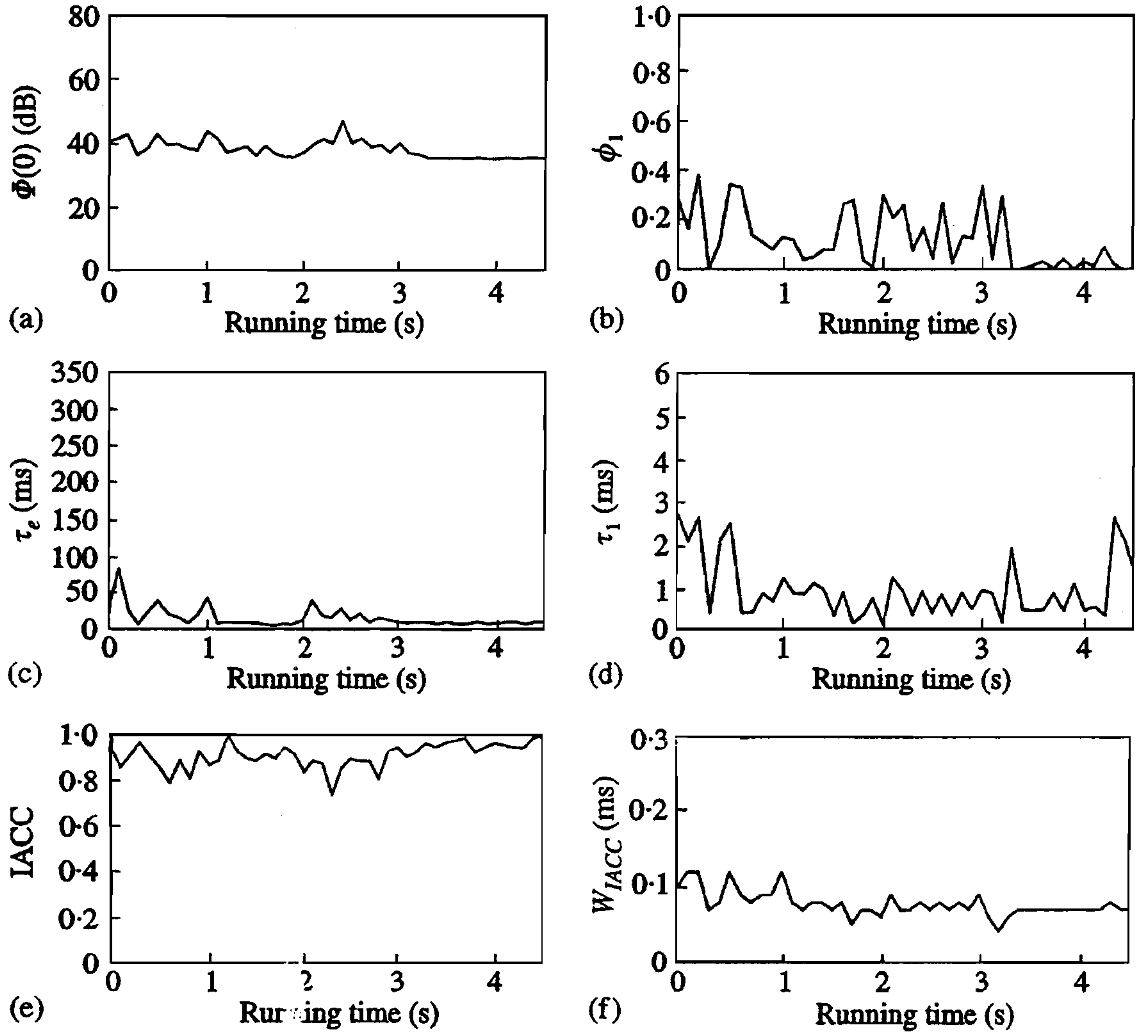

Figure 3.6 Analysis of the running ACF and the running IACF of voice with 2T=0.1 s: (a) $\Phi(0)$; (b) ϕ_1; (c) τ_e; (d) τ_1; (e) IACC; (f) W_{IACC}.

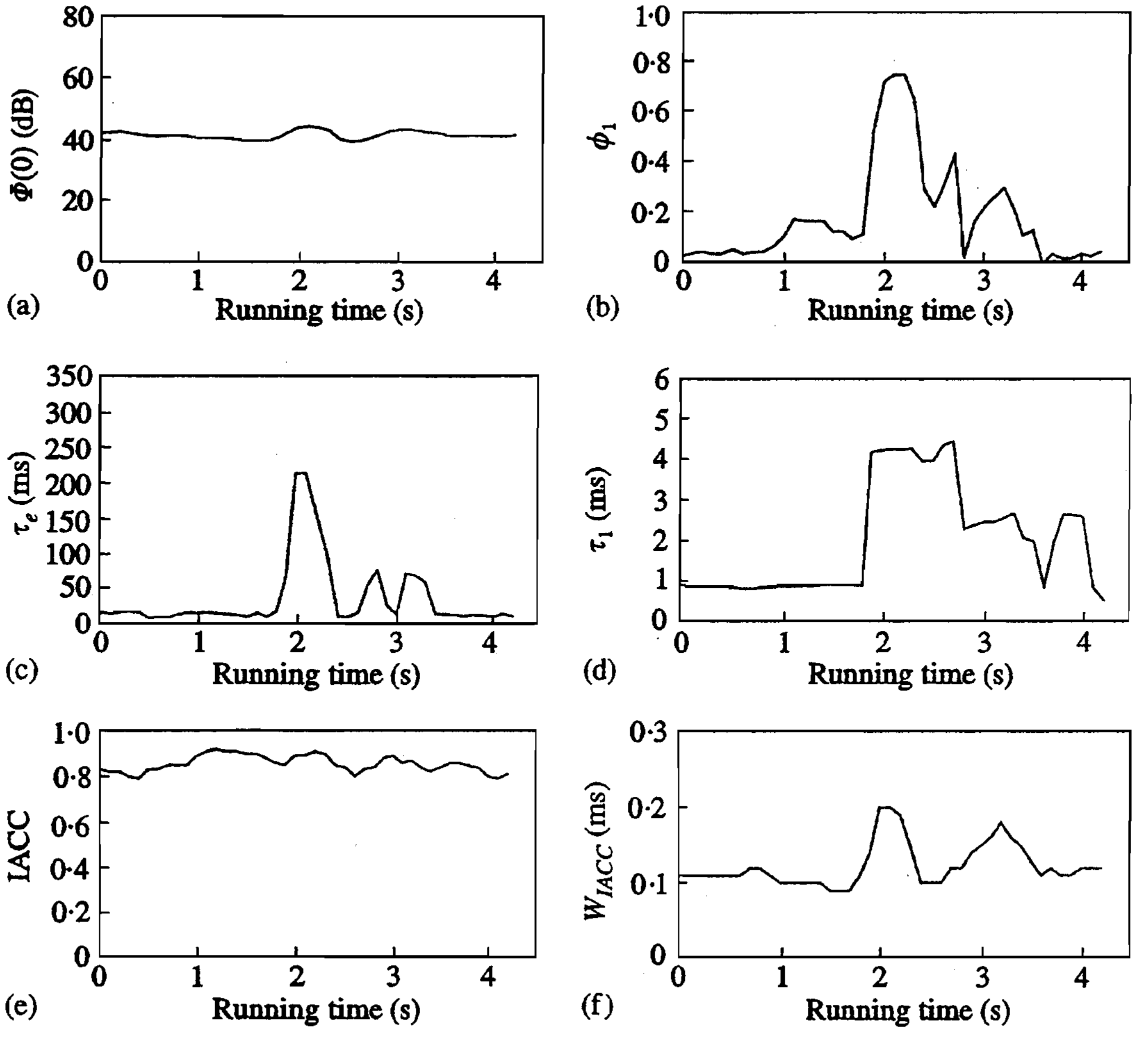

Figure 3.7 Analysis of the running ACF and the running IACF of music I with 2T=0.2 s: (a) $\Phi(0)$; (b) ϕ_1; (c) τ_e; (d) τ_1; (e) IACC; (f) W_{IACC}.

Firstly, the correlation coefficients among each physical factors ($\Phi(0)$, ϕ_1, τ_e, and τ_1) were investigated. Secondly, the wave forms of $\Phi(0)$, ϕ_1, τ_e, and τ_1 for each 2T was compared to its hearing impression respectively, and the 2Ts, which corresponded to the hearing impression of the wave form, were selected for each sound sources. Thirdly, the 2Ts were investigated according to the minimum value of effective duration (τ_e)min because (τe)min is considered to be one of the most important factors for perception of timbre [1]. This 2T is expressed as (2T)r.

These analysis were carried out by use of the Real time sound analyzer (Yoshimasa electronic inc.). Data was recorded from two microphones fixed at left and right ear of real head with the sampling rate of 44.1 kHz.

3.4. Results and discussion

First of all, the correlation coefficients of $\Phi(0)$, ϕ_1, τ_e, and τ_1 of voice and fan noise of the air conditioner and personal computer are low, because the factors are theoretically orthogonal with each other. But, those of key - punch, telephone ring, music H and music I are apparently high, for example, the value of music I between $\Phi(0)$ and ϕ_1 is 0.82. These may be resulted by a rhythmical sound, particularly relating to τ_e and τ_1 (see Table 1). The relationship between wave form and hearing impression was observed in the $\Phi(0)$ and τ_1, but was not found in ϕ_1 and τ_e, because these factors might be masked by $\Phi(0)$ and τ_1. The typical example is shown in Figure 3.1 and Table 3.2. Additionally, the recommended 2Ts of $\Phi(0)$ and τ_1 was correspondent with each other. For the fan noise of the air conditioner, the key - punch noise, the fan noise of the personal computer and the human voice, the value of (2T)r is recommended as 0.1 s. The telephone ring and music I, 2T = 0.2 s, and for music H it is 0.4 s. Each waveform of the running ACF and IACF is shown in Figures 3.2 to 3.7. The value of τ_{IACC} of telephone ring has some variance resulting from the movement of the head, because the microphones were fixed at the ear - entrances of the real head, but those of other sound sources are almost 0. The relationship between values of (2T)r and (τ_e)min is illustrated in Figure 3.8. Obviously, linear relation is observed between the log 2T and log (τ_e)min, and its regression line is approximately expressed as following equation.

$$(2T)r \approx 0.03\,(\tau_e)\mathrm{min} \qquad [s] \qquad (1)$$

Table 3.1 Correlation coefficients above 0.7 among physical factors

Sound source	Physical factors	correlation coefficient
key - punch	$\Phi(0)$ and ϕ_1	0.75
music H	ϕ_1 and τ_1	0.79
	ϕ_1 and τ_e	0.86
music I	$\Phi(0)$ and ϕ_1	0.82
	$\Phi(0)$ and τ_e	0.82
Telephone ring	$\Phi(0)$ and τ_e	0.77
	ϕ_1 and τ_1	0.78

Table 3.2 Example of judgement of hearing impression for several 2Ts (music I)

$2T$ (s)	0·1	0·2	0·4	1·0	2·0
Viewpoint $\Phi(0)$	△	○	△	×	×

Note: (○), well matched; (△), mildly matched; (×), little matched.

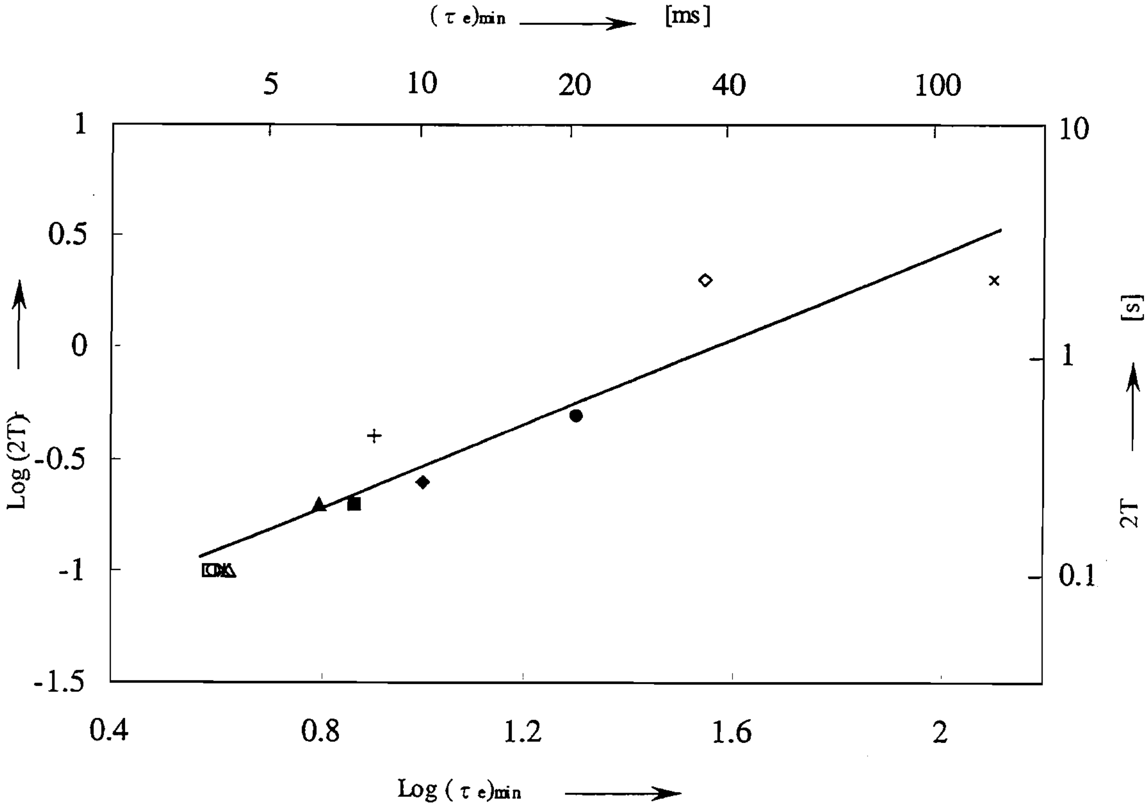

Figure 3.8 Relationship between (2T)r and (τe)min: ▲, telephone ringing; ○, fan noise of air conditioner; ∗, key-punch; △, fan noise of PC; □, voice; +, music H; ■, music I; ×, motif A; ◇, motif B [5]; ●, aircraft noise A; ◆, aircraft noise B

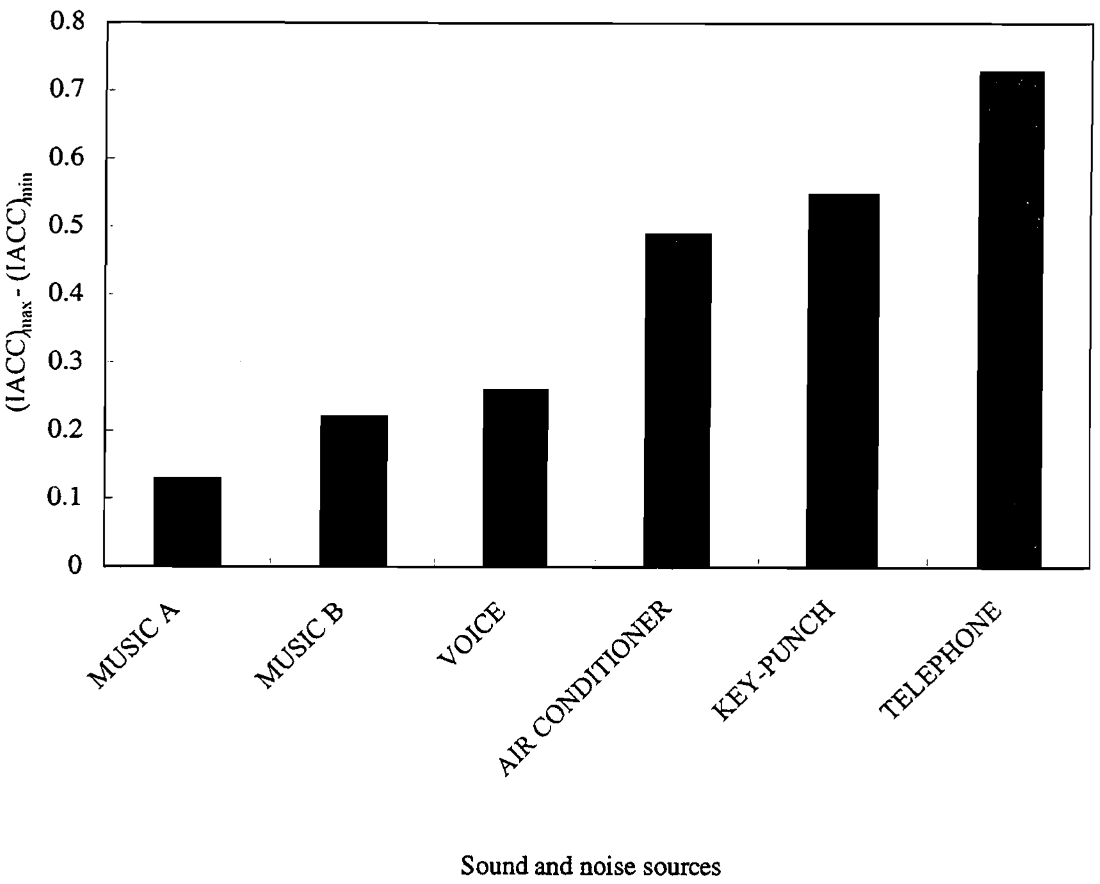

Figure 3.9 Maximum range of IACC for the noise in an office.

This result suggests that the integration interval of human auditory - brain system may be changed by the (τ_e)min of sound sources.

Additionally, according to the IACF, it was found that IACC is affected by the kind of sound sources, as shown in Figure 3.9, but the fan noise of the personal computer was eliminated from this figure because it was recorded in the office and others were recorded in anechoic chamber. In the case of key - punch and telephone ring, the sound is intermittent, so that IACC might be changed. On the other hand, the IACC of the continuous noise of the air conditioner is changed because of its strong low frequency, as shown in Figure 3.3(d).

Thus, the minimum duration of hearing perception is closely associated with the effective duration of the sound signal.

Chapter 4

Effects of telephone ring on two mental tasks relative to an office

4.1. Introduction

There are many kinds of noise sources in an office, and telephone ring is often considered as one of the most irritating sound for almost office workers. Prior to this study, Ando [1, 2, 3] demonstrated that left hemispheric verbal task is interrupted by ipsi - lateral sound and *vice versa* for right hemispheric task. But these effects have not been described by the physical parameters of the sound signals yet. Recently, it is revealed that subjective attributes have been well estimated by the autocorrelation function (ACF) and the interaural cross - correlation function (IACF) [4].

The purpose of this study is to investigate the effects of telephone ring on two mental works relating to the physical factors extracted from the sound signal.

In this study, the sound effects were evaluated by V - type relaxation which is associated with hemispheric specialization. V - type relaxation is thought to be caused by an abandonment of effort when mental functions are unbalanced or disordered [1, 2, 3].

4.2. Procedure

Ten office workers were chosen as the experimental subjects. They were approximately within the ages of 25 to 35 year old and right handed. Prior to this research, they were confirmed to have normal hearing ability.

They were separated in two groups (A, B). Each group had five subjects. The subjects of the group A performed the adding task and those of the group B performed the drawing task. In this investigation, the adding task was chosen as a left hemispheric task and the drawing task was chosen as a right hemispheric task, as shown in Figure 4.1.

Each subject was required to carry out these tasks as fast as possible and to start from the first period ($i = 1$) when the 1 kHz signal of short duration was given and after 1 min. start a new set of problems ($i = 2, 3, ..., N$) as soon as the same signal was given. Each task was divided into a first and a second half and there was an interval of 5 min for rest. The total time was 35 min for the adding and drawing tasks ($2N = 30$).

Telephone ring, which was recorded by the digital audio tape with the sampling rate of 48 kHz, was given every two period with the sound pressure level of no - stimuli (25dBA: background noise) 40 and 80 dBA in the anechoic chamber. These conditions were selected randomly for each subject. The loudspeaker was placed at the distance of 1.5 m ± 1 cm in front of the subject. The running ACF and IACF of telephone ring were measured by the diagnostic system of sound fields [5] with the integration interval of 0.2 s.

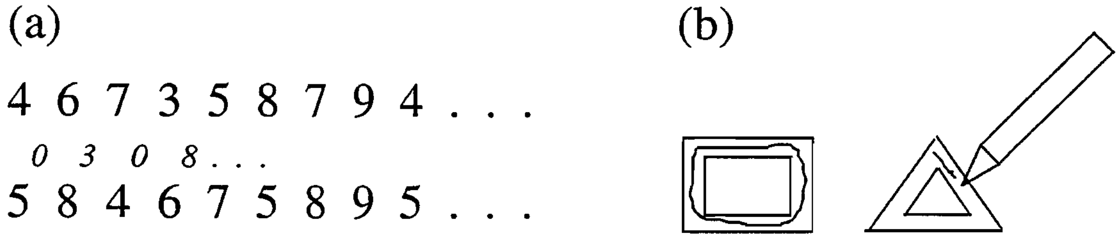

Figure 4.1 Mental task: (a) adding task; (b) drawing task.

4.3. Evaluation of mental task

First, the individual work produced in each period, which is called the "working curve", was drawn for all test results. In this investigation, the following scores were calculated, based on the working curve.

$$\overline{M}_1 = \frac{1}{N}\sum_{i=1}^{N} M_i, \qquad \overline{M}_2 = \frac{1}{N}\sum_{i=N+1}^{2N} M_i$$

The score of V - type relaxation is classified into two categories according to the occurrence of a sudden large fall in the working curve during each half of the task, as shown in Figure 4.2. V - type relaxation was assumed by

V_1: $M_i < \overline{M}_1 - \frac{3}{2}W_1$ ($i = 1, 2, \ldots, N$),

V_2: $M_i < \overline{M}_2 - \frac{3}{2}W_2$ ($i = N + 1, N + 2, \ldots, 2N$),

where W_1 and W_2, which are defined here as the variances of the curve excluding the periods of $i = 1$ and $N + 1$ which usually give a large amount, may be calculated. Thus a subject was regarded as showing relaxation if any period showed a fall in output below

(3 /,2)Wj (j = 1, 2).

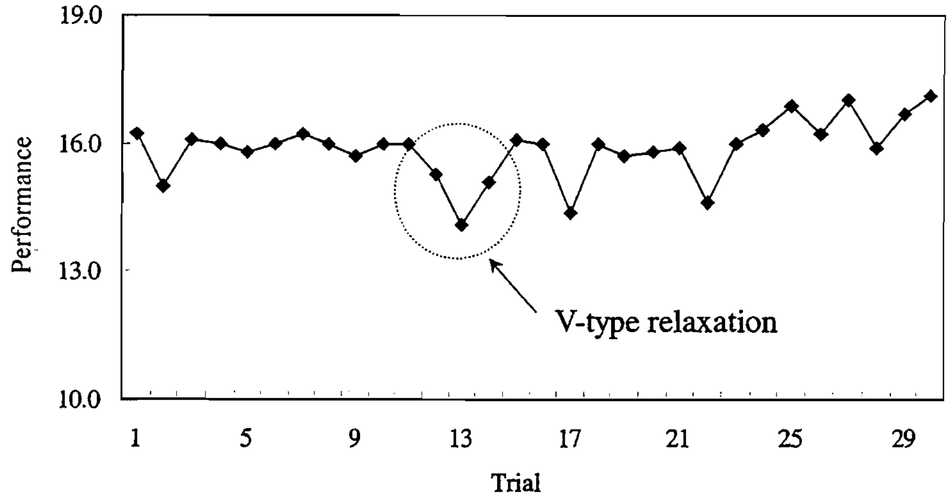

Figure 4.2 Example of "working curve" and V-type relaxation.

4.4. Results and discussion

As indicated in Table 4.1, V - type relaxation occurred during the drawing task only, and the relaxed population was increased significantly under the conditions of both 40 and 80 dBA of the telephone ring (see Figure 4.3 also). However, a similar result was not observed during the adding task. Considering the cerebral hemispheric specialization, an interference effect may occur in the performance of hemispheric tasks because the left and the right hemispheres are associated with the temporal and the spatial factors of sound fields which are extracted from ACF and IACF, respectively [4]. In this experiment, the drawing task is regarded as right hemispheric spatial task. According to the theory of the ACF and the IACF models, it is assumed that right hemisphere processes the spatial factors of the IACF of the telephone ring. Namely, it is considered that some features of IACC, LL (listening level), W_{IACC} or τ_{IACC} influenced to the drawing task typically because these physical parameters are extracted from IACF [6].

Previously, IACC and LL have been demonstrated as right hemispheric parameter by use of the physiological method [7]. Additionally, it was observed that variances of the running IACC and LL of telephone ring were large, as shown in Figures 4.4 and 4.5. Therefore, it might be concluded that the right hemispheric drawing task is affected by rapid change of IACC and LL. On the other hand, the left hemispheric adding task was not influenced by a minor change of running τ_e and τ_1 of the telephone ring, extracted from ACF, because the noise did not contain any specific information activating the left hemisphere.

Table 4.1 Significant differences of V-type relaxation obtained by Sign test for each sound environment on two mental tasks.

Task	V - type relaxed subjects / Number of subjects		
	BN	40 dBA	80 dBA
Adding task	0 / 5	0 / 5	0 / 5
Drawing task	2 / 5	5 / 5*	5 / 5*

BN: Background noise (25 dBA); *: $p < 0.05$.

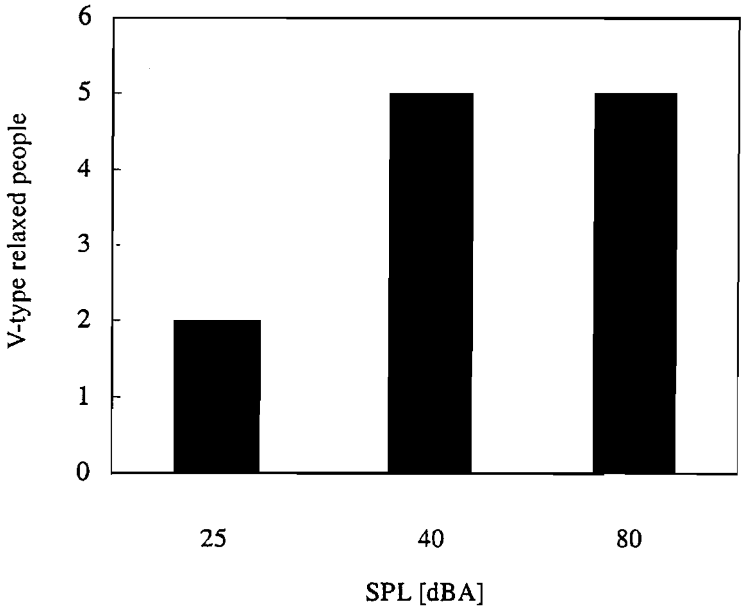

Figure 4.3 V-type relaxed people for the drawing tasks under the telephone ringing.

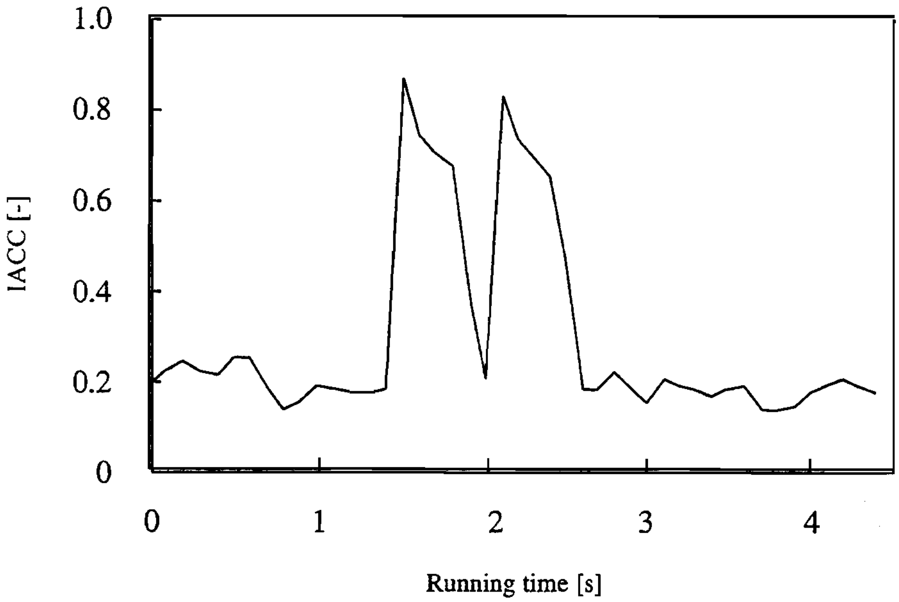

Figure 4.4 Analysis of the running IACC of telephone ringing with 2T = 0.2.

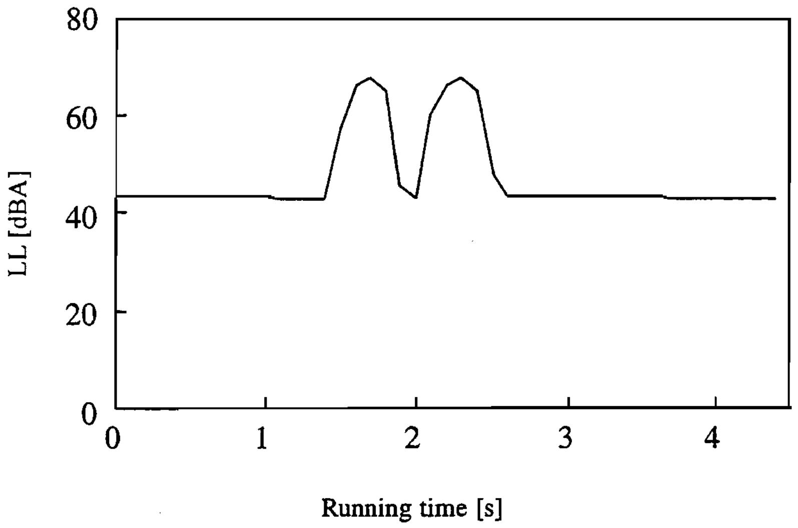

Figure 4.5 Analysis of the running LL of telephone ringing with 2T = 0.2.

Chapter 5

The role of the interaural cross-correlation function relating to the moving sound image for the band noise

5.1. Introduction

A workable model of human auditory brain system, including hemispheric specialization, is proposed by Ando [1]. This model consists of process in auditory system of the autocorrelation function (ACF) and the interaural crosscorrelation function (IACF) of sound signal, and the specialization of the left and right cerebral hemisphere. Additionally, the information extracted from ACF and IACF mechanism are processed on the left and right hemisphere, respectively. Both functions are shown in chapter 1.

By using $\Phi(0)$, ϕ_1, τ_e, τ_1, τ_{IACC}, IACC and W_{IACC}, subjective attributes have been well described [2, 3, 4, 5]. It is considered that the binaural system, relating to IACF mechanism, plays important role for the spatial sensation of sound environment [6]. Subjective diffuseness, apparent source width and the sound localization on the horizontal plane have been well described by the physical factors extracted from IACF [6, 7, 8]. Recently, using Positron emission tomography (PET), Griffiths has identified cortical areas (the right insula) that appeared to be selectively activated while human subjects attended to the position of a moving sound image compared to when they attended to a stationary sound image [9]. Baumgart also suggested that right auditory cortex processes the information of the moving sound image by using functional magnetic resonance imaging (fMRI) [10]. Obviously, these findings support that the information of IACF mechanism is processed on the right hemisphere. Therefore, it is important for explaining the relationship between sound stimuli and human subjective responses to analyze ACF and IACF mechanism. This study focused on 2T (the integration interval which is considered as temporal window in this study). Considering the psychological present [11], the temporal window of ACF and IACF was fixed at 2 s approximately in the previous investigations. But, this definition is not clearly. For this reason, this paper attempts to determine the temporal window of IACF to be analyzed in relation to the moving sound image. Mouri et al. described that the temporal window of ACF mechanism is relating to the (τ_e)min (minimum value of τ_e) of sound signals, and showed that the recommended temporal window of ACF mechanism is predicted by the (τ_e)min of the source signal [12]. This investigation reveals that human temporal window of ACF mechanism is affected by the temporal properties extracted from the sound source. Therefore, it is hypothesized that the temporal window of IACF also associated with the factors relating to the temporal changes, (τ_e)min or the moving properties of sound signal. In this study, an attempt is made to determine the temporal window of IACF for sinusoidal moving sound image in the horizontal plane whose source signal is band noise modulated in amplitude. It is considered that the sound localization on the horizontal plane is well described by τ_{IACC}. First of all, the relationship between τ_{IACC} and the azimuth of sound source was measured. Then, the influence of the moving periods in terms of modulated signals produced by two loudspeakers with bandpass noise centered on 500 Hz was examined by changing the temporal window of IACF.

5.2. Preliminary study on localization for fixed source in azimuth

5.2.1. Measurement of τ_{IACC}

The relationship between the azimuth of incidence of sound source and τ_{IACC} has not been defined yet. Therefore, the relation was investigated for the static sound source first of all in this experiment. τ_{IACC} is defined as the interaural time delay of IACF (see Figure 1.3). The 1/3, 1 and 2 octave band noise of center frequency of 500 Hz with the duration of 5 s, which were synthesized from white noise by use of Butterworth filter with the order of 18, were utilized for sound sources. These sound were reproduced from the loudspeaker (Fostex: FE-87E) located around the dummy head, whose diameter was 0.2 m with two microphones, in the anechoic chamber where background noise level was about 25 dBA. The distances between the loudspeaker and the dummy head were 0.6 and 1.0 m. The sound pressure level was fixed at 70 dBA. The sound signals were recorded with the sampling rate of 44.1 kHz by the special sound analyzing system (Yoshimasa electro. Inc.), and τ_{IACC} was calculated through the A-weighted network. As shown in Figure 5.1, it was found that the relationship between τ_{IACC} and the azimuth was varied by the bandwidth, and the values of τ_{IACC} slightly tend to decrease with increasing bandwidth. Generally, sound localization on the horizontal plane has been described by Duplex theory, in which sound localization is explained by the interaural time difference (ITD) and interaural level difference (ILD), when the sound source is pure tone [13, 14]. According to this theory, it is assumed that ITD is dominant for the band noise of 500 Hz, and it is predicted that ITD has the maximum value of about 0.75 ms, but τ_{IACC} is exceeded 0.8 ms. This value corresponds to the traveling duration of direct sound from one microphone to another along the surface of the dummy head, approximately. It is considered that τ_{IACC} contains the information of ITD, ILD and some other characteristics like wave form. Therefore, the value of ITD is not consistent with τ_{IACC} exactly. Feddersen researched the interaural time difference relating to the direction of sound source by use of click sound through earphones, and obtained the similar result [15]. This figure was utilized in next localization test.

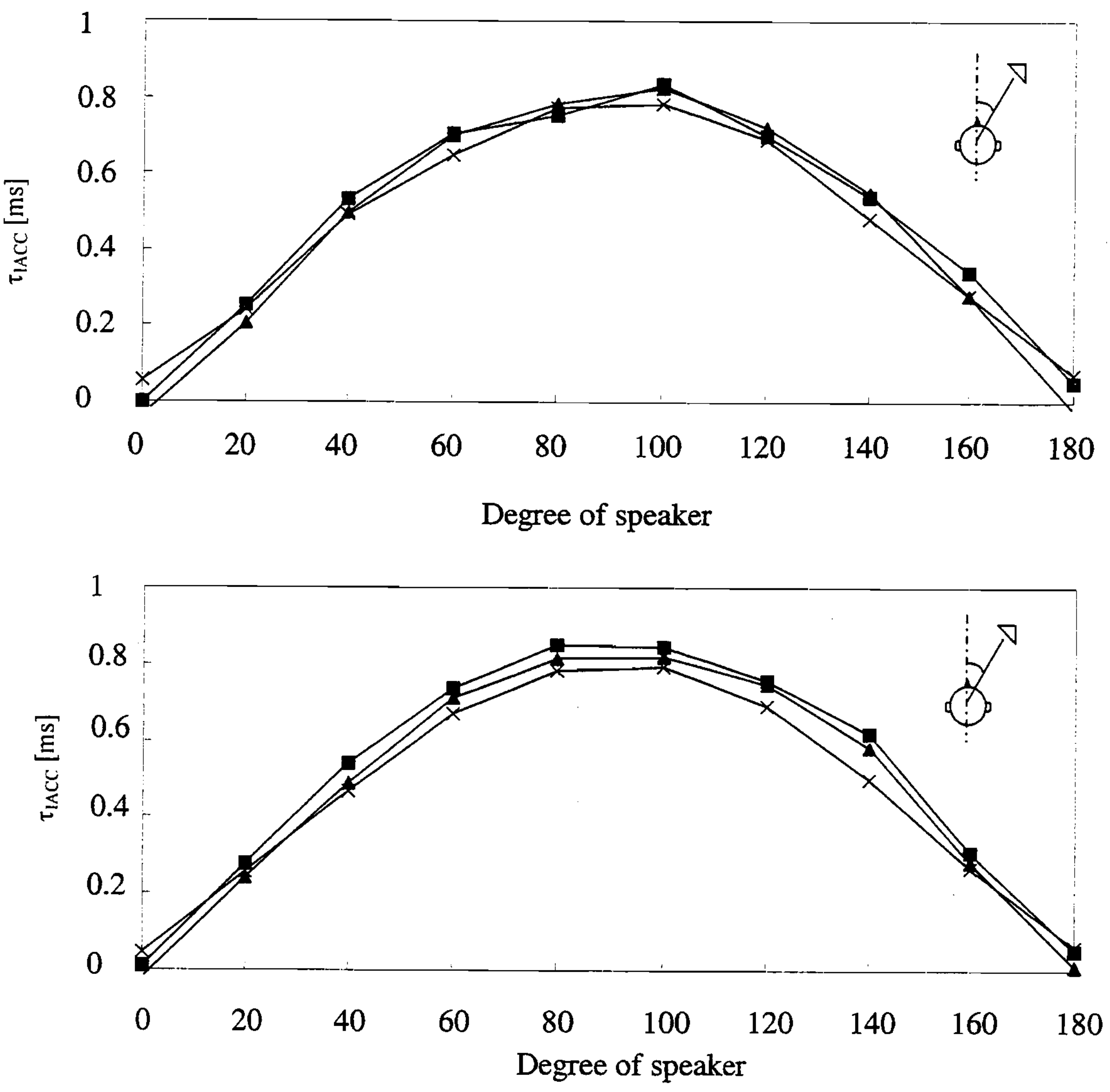

Figure 5.1 Relationship between τ_{IACC}s of sound sources and the azimuth on the horizontal plane [the distance between dummy head and speaker is 1.0 m (upper) and 0.6 m (lower)]; ■: 1/3 octave, ×: 1 octave, ▲: 2 octave.

5.2.2. Localization test

Secondly, subjective azimuth was estimated. Ten subjects with normal hearing were participated in this experiment. The same sound sources were utilized for stimuli. Each sound was reproduced by the computer system with the sampling rate of 44.1 kHz through the same speaker. And the speaker's location was selected at the azimuth of 20° or 60° in front of the subject in the anechoic chamber. The height of the speaker was fixed at 1.1 m from the floor, and the distance from the subjects was 0.6 m. The sound pressure level was fixed at about 70 dBA. Subjective azimuths were estimated five times for each condition (4 stimuli * 2 azimuths) with random order. Subjects were required to point the direction where they feel the stimuli.

Result shows that the subjective azimuths are well correspond to the actual azimuths for all source signals (see Figure 5.2). The effect of bandwidth was not significant for the subjective azimuth [see Table 5.1 (a) and (b)].

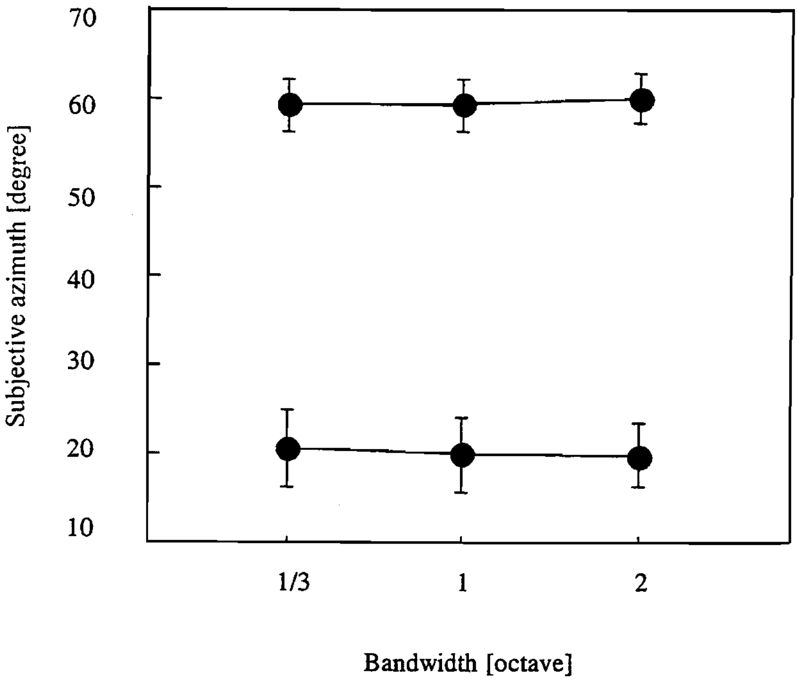

Figure 5.2 Effects of bandwidth for subjective azimuth.

Table 5.1 (a) Analysis of variance for bandwidth relating to subjective azimuth on the actual azimuth of 20° .

Factor	Degree of freedom	Sum of square	F-value
Bandwidth	3	127.78	2.50
Error	176	3002.22	

***: p < 0.05, **: p < 0.01**

Table 5.1 (b) Analysis of variance for bandwidth relating to subjective azimuth on the actual azimuth of 60° .

Factor	Degree of freedom	Sum of square	F-value
Bandwidth	3	54.44	1.95
Error	176	1636.67	

***: p < 0.05, **: p < 0.01**

5.3. Determining temporal window of IACF

The same subjects were participated in this experiment also. The amplitude modulated band noise was used as stimulus sounds to investigate the relationship between the image shift of sound and τ_{IACC}. The stimulus sounds were the band noise of center frequency of 500 Hz whose bandwidth was 1/3, 1 or 2 octave. The amplitude of these stimuli was modulated to arise the image of moving of sound, and were reproduced through the two loudspeakers (Fostex: FE-87E) located at the azimuth of ± 20° toward the subject in the anechoic chamber (see Figure 5.3).

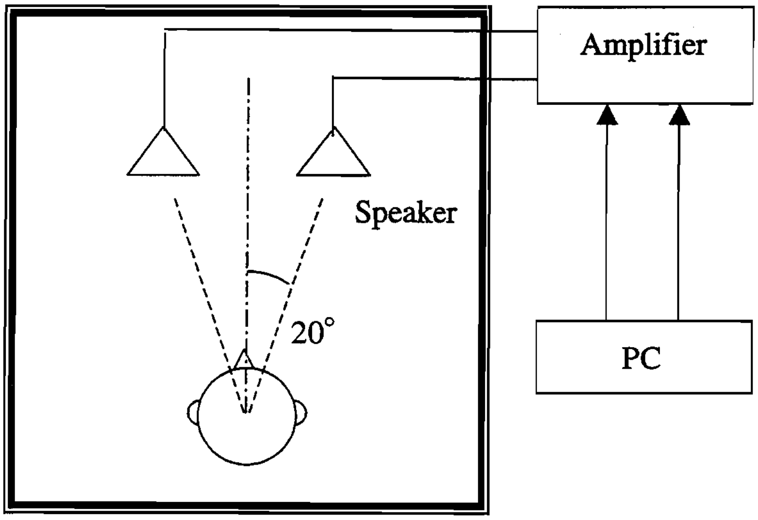

Figure 5.3 Location of speakers and block diagram.

The amplitude of the band noise was modulated to make subjects feel the moving sound image on the horizontal plane. The sound pressure level of one speaker was increased to 70 dBA and decreased to 0 dBA sinusoidally to another speaker, alternatively (see Figure 5.4). The modulation frequencies were selected 0.1, 0.2, 1, 2 and 4 Hz in this investigation. Each sound was reproduced by the computer system with the sampling rate of 44.1 kHz. Each subject was required to point the left and right sides where they can feel the moving image of the stimulus sound under the selected condition with their left and right arms, and the angle between both arms was defined as subjective angle in this paper. These measurements were repeated five times for one stimulus condition with random order. Then, subjective angle was obtained. Figure 5.1 was plotted again as Figure 5.5 to convert subjective angle into the range of τ_{IACC} because subjective angle is strongly relating to the range of τ_{IACC}. The temporal window of IACF mechanism was chosen for the range of τ_{IACC} corresponds to subjective angle.

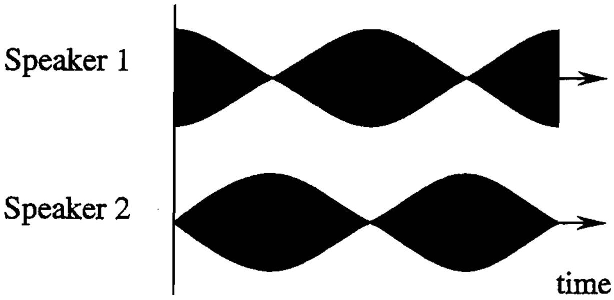

Figure 5.4 Modulated sound stimuli reproduced from two speakers system.

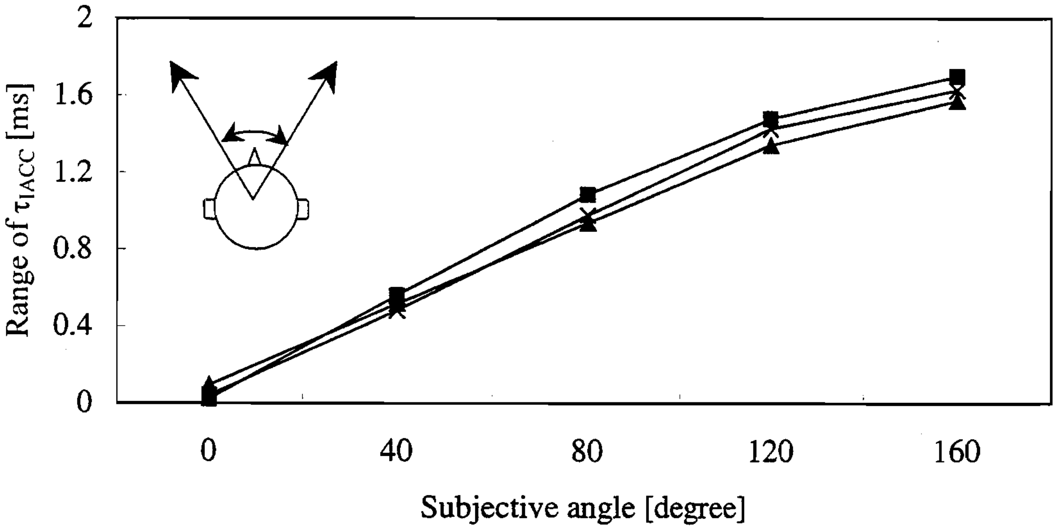

Figure 5.5 Relationship between subjective angle and range of τ_{IACC}.

5.4. Results

Prior to the analysis, the data of subject J was eliminated because of less reliability. According to analysis of variance relating to the subjective angle, the effect of bandwidth was significant ($p < 0.05$), and the subjective angle was largest when the bandwidth was 2 octave. This tendency is observed from 5 subjects (n.s). The effect of modulation frequency is highly significant ($p < 0.01$) also, but the interference effect between bandwidth and modulation frequency is not significant (see Table 5.2). As shown in Figure 5.6, subjective angle of incidence of sound is increased when the modulation frequency is decreased. This result is observed from almost subjects (see Figure s 5.7 to 5.9). The subjective angle was largest (about 57°) when the modulation frequency is below 0.2 Hz. This angle corresponded to the range of τ_{IACC} of about 0.6 ms, as shown in Figure 5.5.

The range of τ_{IACC} was strongly influenced by the temporal window of IACF. It was confirmed that the longer temporal window is increased, the narrower range of τ_{IACC} becomes, as shown in Figure 5.10. This tendency was summarized for each modulation frequency in Figure 5.11. The range of τ_{IACC} of 0.6 ms was obtained when the temporal window is from about 0.03 to 1 s. When we focused on the subjective angle with modulation frequency of below 0.2 Hz, it is found that the value of temporal window of IACF is distributed from 0.03 to 1 s, approximately. And, the relationship between temporal window and range of τ_{IACC} is similar for the different band noise, whereas the (τ_e)min of the 1 / 3 octave band noise is shorter than that of 1 and 2 octave band noise, as shown in Figure 5.12.

Table 5.2 Analysis of variance for bandwidth and modulation frequency relating to subjective angle.

Factor	**Degree of freedom**	**Sum of square**	**F-value**
Bandwidth	2	639.19	3.91*
Modulation frequency	4	21254.95	64.93**
Bandwidth* Modulation frequency	8	479.89	0.73
Error	660	54015.82	

***: $p < 0.05$, **: $p < 0.01$**

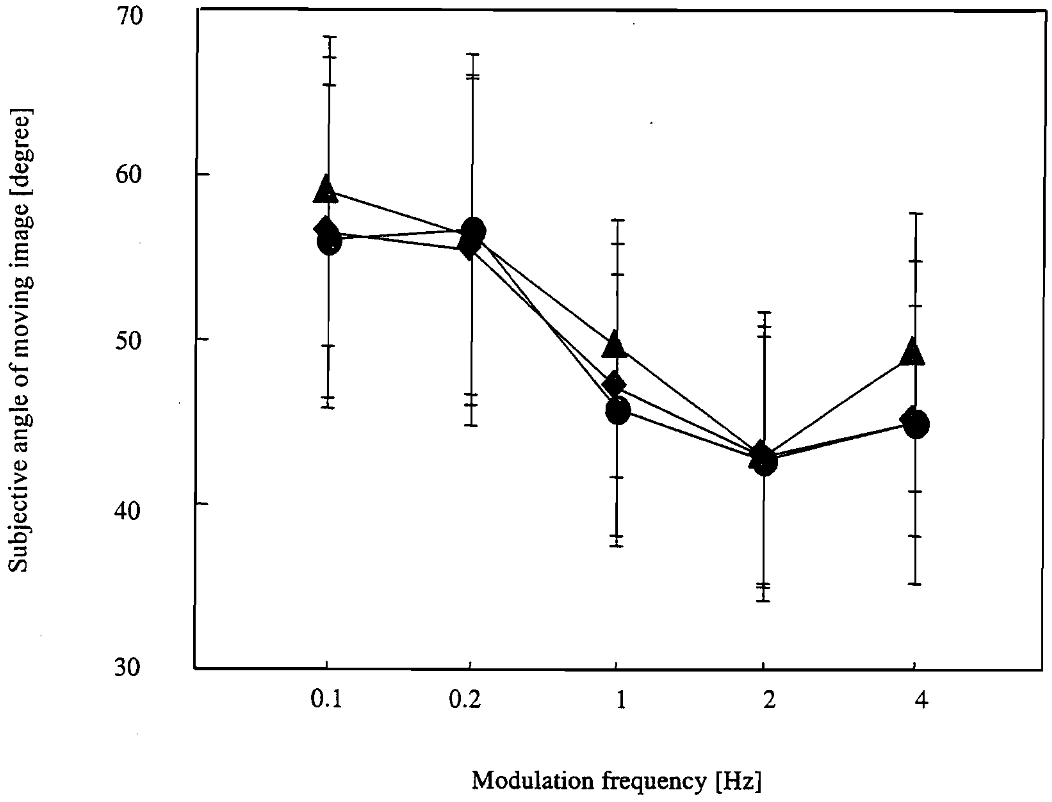

Figure 5.6 Global results on the relationship between subjective angle and modulation frequency (error bar means the standard deviation); ◆: 1 / 3 octave, ●: 1 octave, ▲: 2 octave.

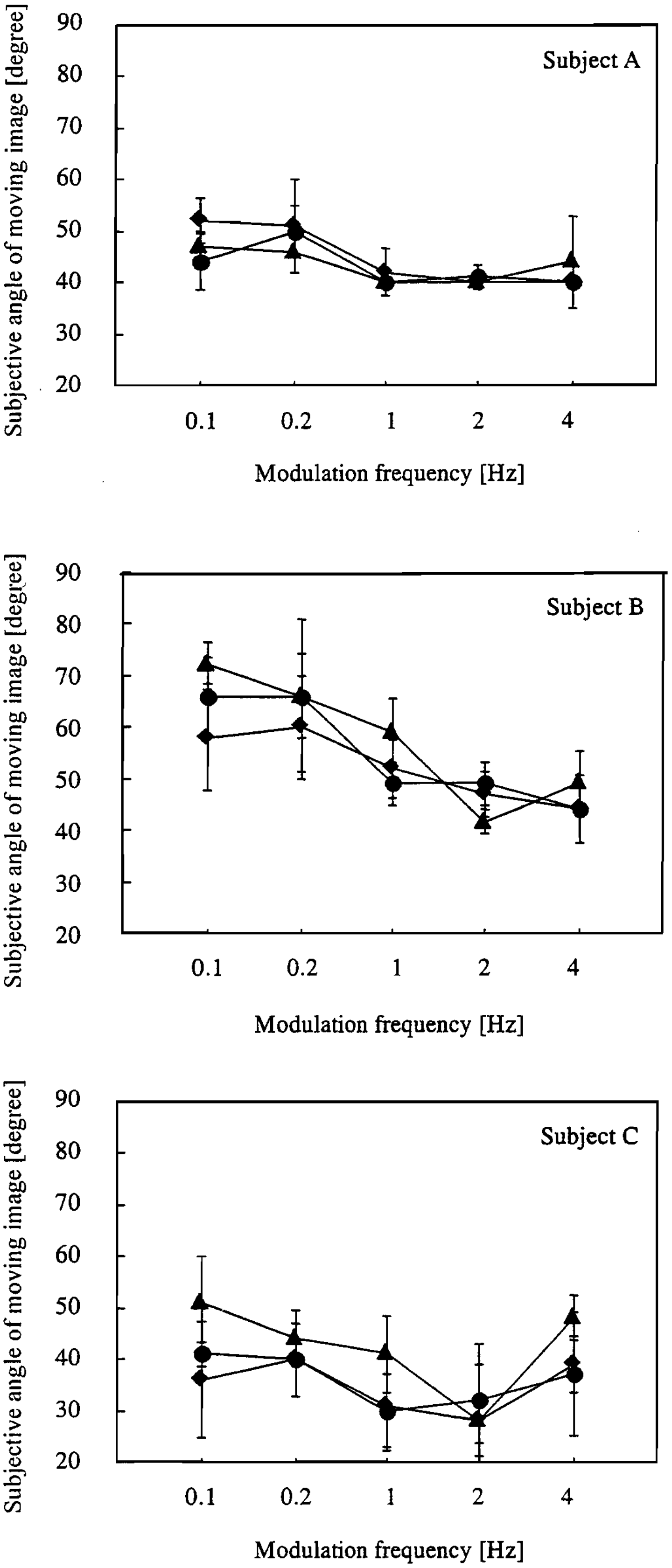

Figure 5.7 Individual results on the relationship between subjective angle and modulation frequency (Subject A - C).

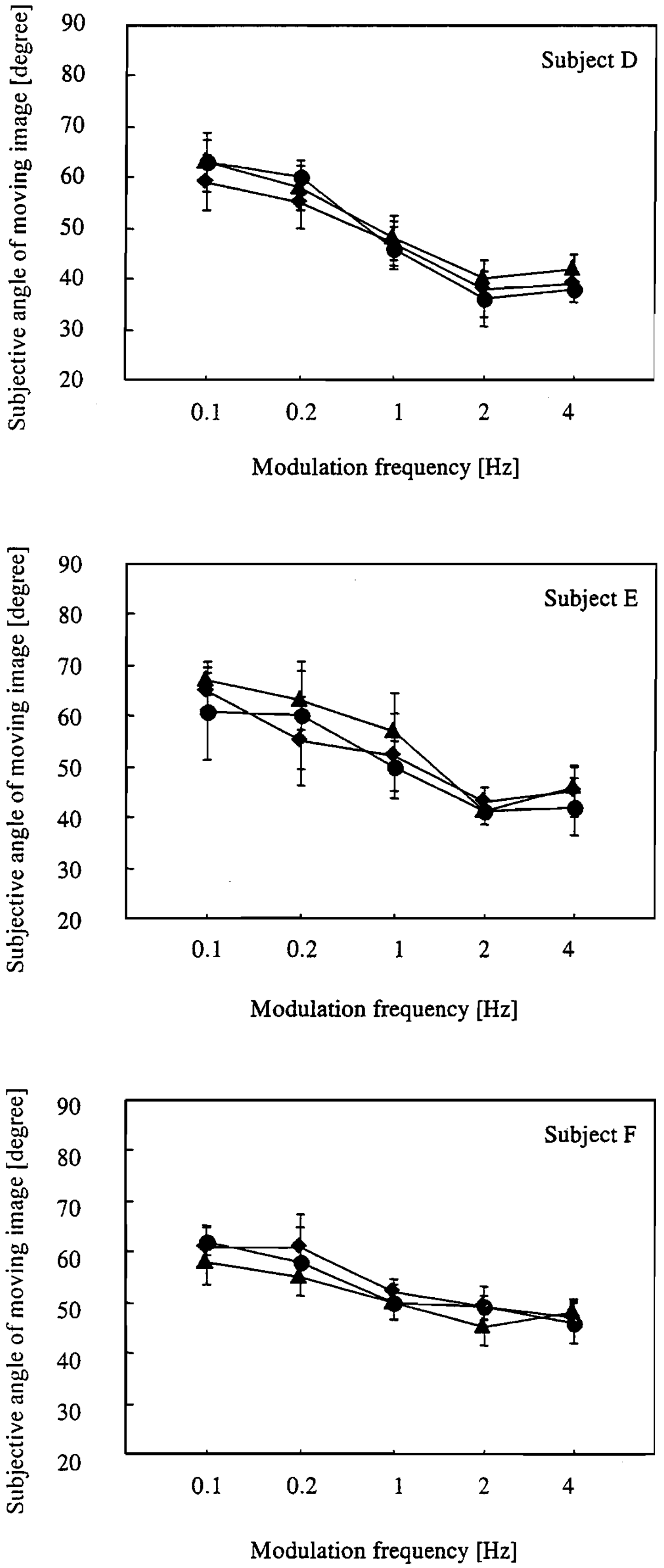

Figure 5.8 Individual results on the relationship between subjective angle and modulation frequency (Subject D - F).

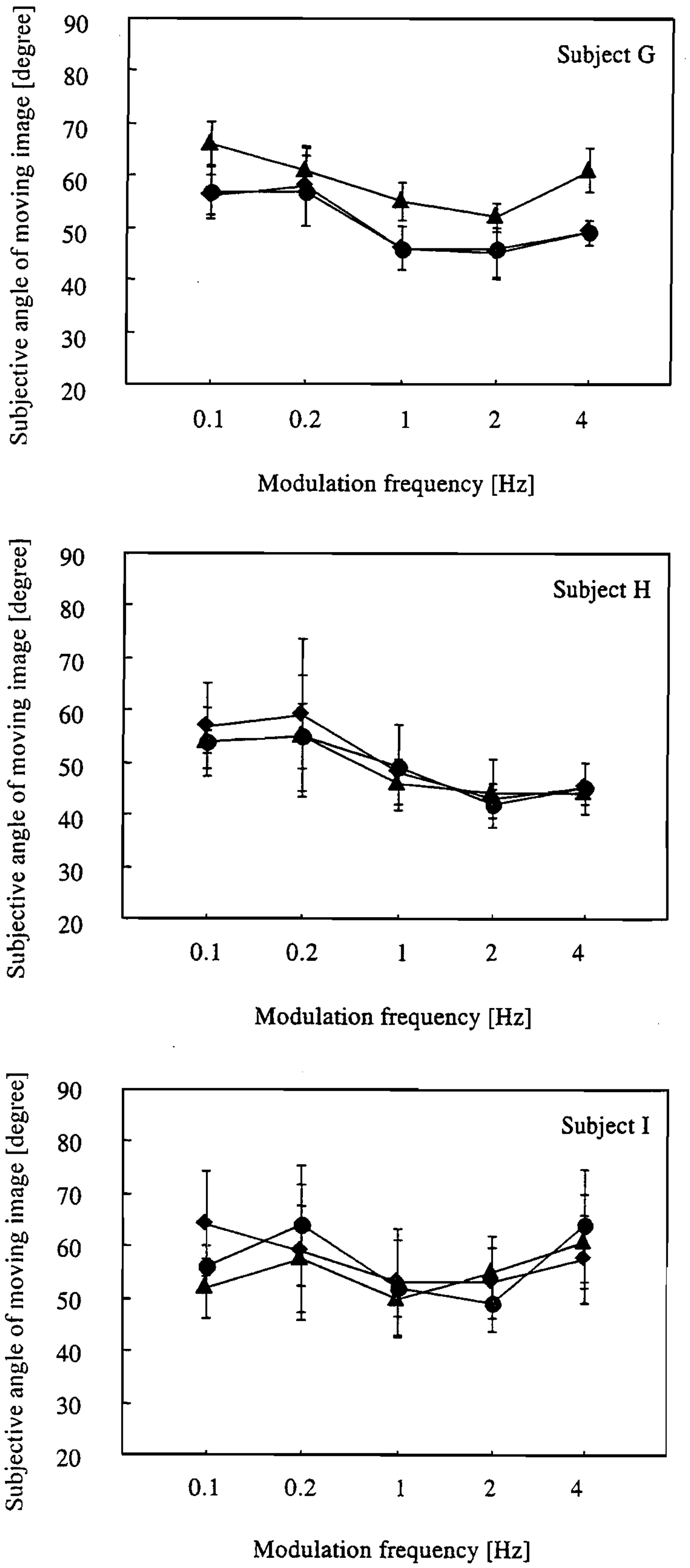

Figure 5.9 Individual results on the relationship between subjective angle and modulation frequency (Subject G - I).

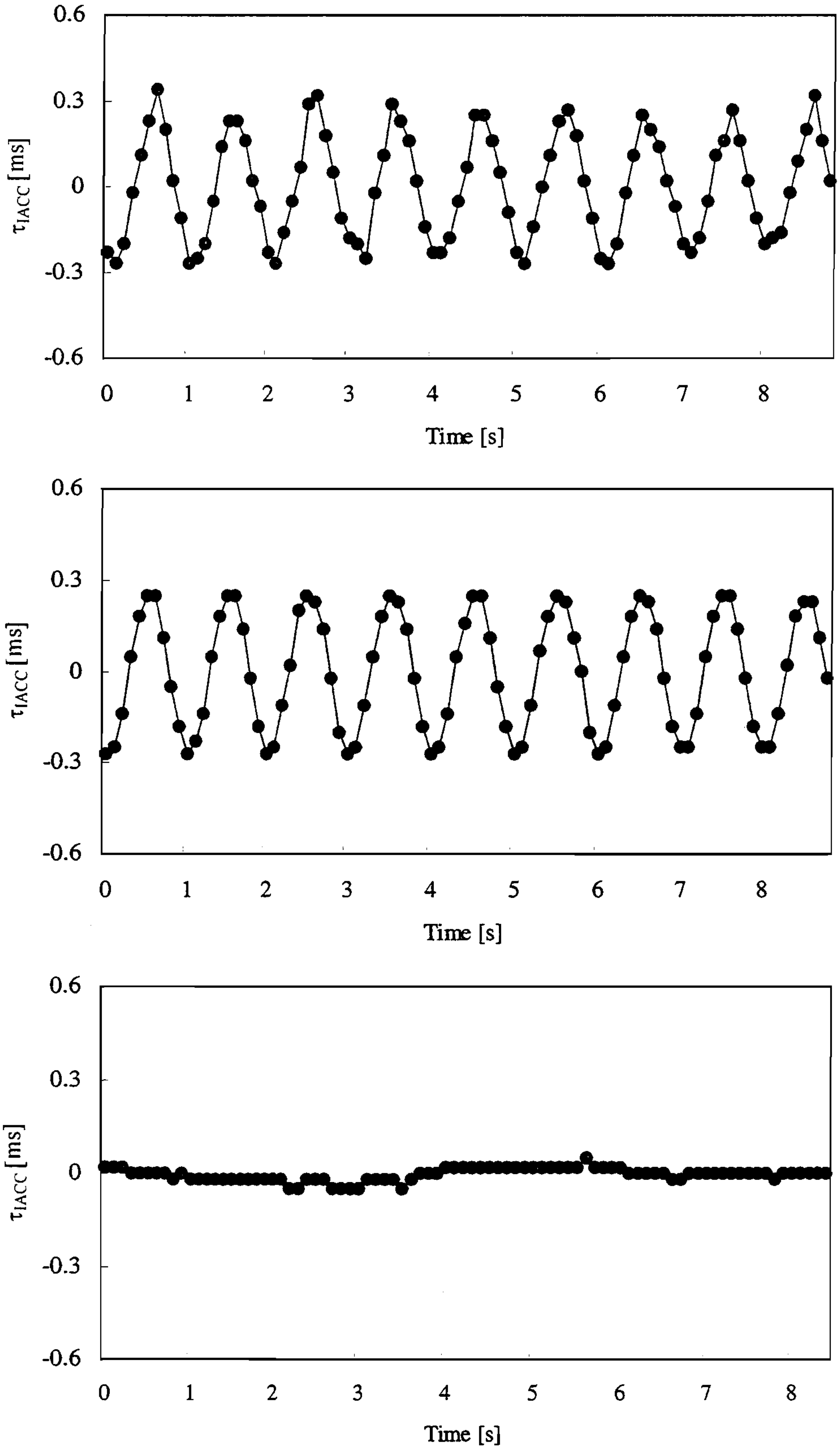

Figure 5.10 Temporal changes of τ_{IACC} (top: 2T = 0.01 s, middle: 2T = 0.1 s, bottom: 2T = 1.0 s).

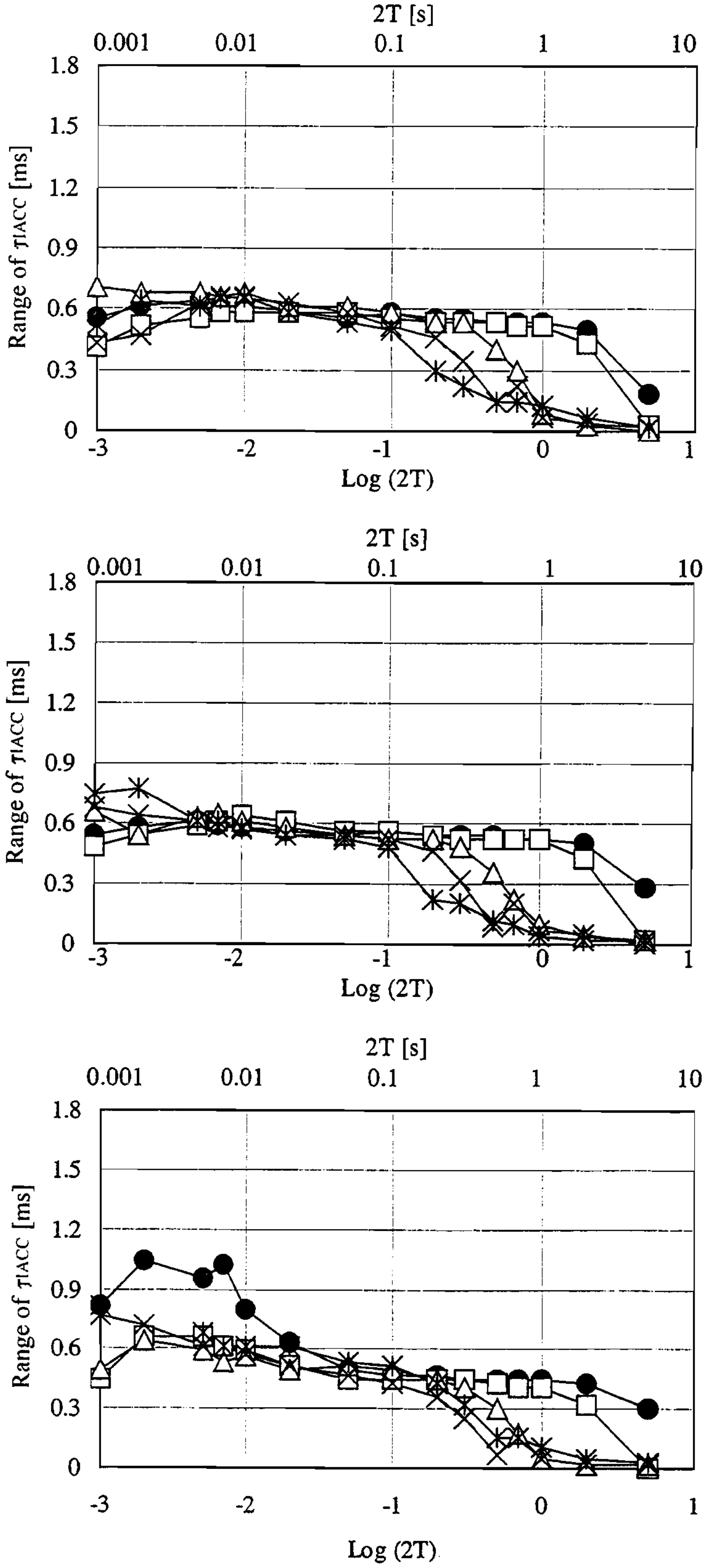

Figure 5.11 Relationship between τ_{IACC} and integration interval for the modulation frequency (top: 1 / 3 octave, middle: 1 octave, bottom: 2 octave) ; ●: 0.1 Hz, □: 0.2 Hz, △: 1 Hz, ×: 2 Hz, ∗: 4 Hz.

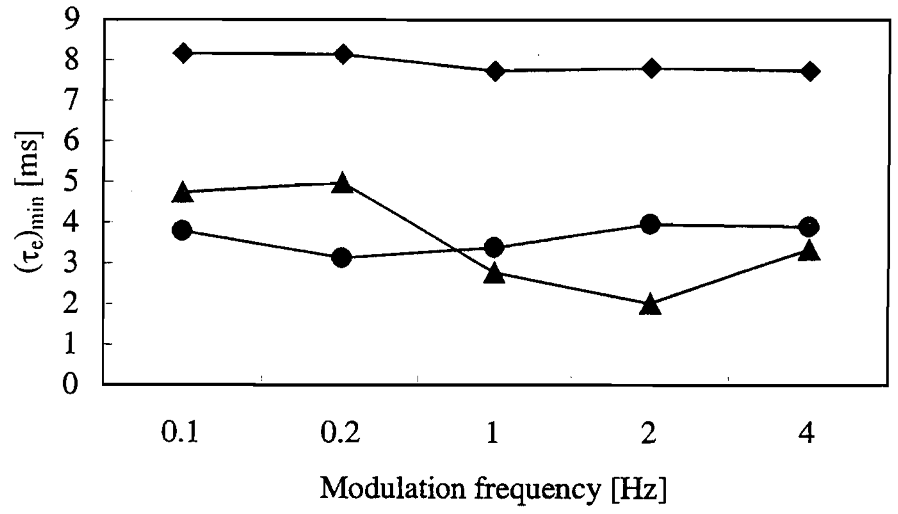

Figure 5.12 Relationship between $(\tau_e)_{min}$ for all modulation frequencies and bandwidths; ◆: 1 / 3 octave, ●: 1 octave, ▲: 2 octave.

5.5. Discussion and conclusions

For the static sound source, it is confirmed that τ_{IACC} becomes a useful factor in judgement of the direction of the source signal in the horizontal plane. This study was carried out to determine the temporal window of IACF mechanism relating to the properties of moving sound image and the bandwidth of noise. It was shown that the temporal window of IACF is found from 0.03 to 1 s, and the values of range of τ_{IACC} obtained correspond well to the subjective angle of moving image, are obtained from this range when the modulation frequency is below 0.2 Hz. The similar result is obtained through the different investigations. Culling and Summerfield revealed that the shape of the binaural temporal window was largely independent of frequency and level, and the windows for individual listeners had equivalent rectangular durations ranging from 55 to 188 ms by using the notched-noise method [16]. On the other hand, Chandler and Grantham reported that the minimum integration time was from 116 to 402 ms for the tone signal of 500 Hz through the studying of minimum audible movement angle [17]. It was assumed that the temporal window of IACF mechanism is affected by the (τ_e)min like that of ACF mechanism and modulation frequency, but this hypothesis was not supported in this study.

6. Summary and conclusions

In this dissertation, the following conclusions were obtained.

(1) It is revealed that subjective preference judged at the (τ_e)min of a source signal is closely related to the value of τ_e of the alpha-brain waves obtained from the left hemisphere. These results mean that the human left hemisphere is sensitive to the most rapid movement of a source signal, and show that the proposed model is acceptable.

(2) The temporal window of the autocorrelation mechanism was expressed as following equation.

$(2T)r \approx 30\ (\tau_e)\mathrm{min}$ [ms] $(r = 0.95, p < 0.01)$

It was found that the temporal window of the ACF mechanism is strongly influenced by the source signal.

(3) It is revealed that the drawing task, which is processed in the right hemisphere, is interrupted by telephone ringing.

(4) It was shown that the temporal window of the interaural crosscorrelation mechanism is from 0.03 to 1 s when the modulation frequency is below 0.2 Hz.

These investigations showed that the proposed auditory-brain system is able to explain subjective attributes and the productivity of mental work, effectively. Additionally, the temporal window of the ACF mechanism is degraded when the variance of the sound signal is fast or large. On the other hand, it was demonstrated that the temporal window of the IACF mechanism for the band noise, whose center frequency is 500 Hz, becomes 0.03 to 1 s approximately.

7. References

Chapter 1

[1] Y. Ando 1998 *Architectural Acoustics, Blending Sound Sources, Sound Fields, and Listeners*, AIP press / Springer-Verlag, New York.

[2] S. Osaki and Y. Ando 1983 A fast method of analyzing the acoustical parameters for sound fields in existing auditoria. *Proc. 4th Comp. Environ. Eng. Build.* (Tokyo), 441-445.

[3] M. R. Schroeder 1965 *J. Acoust. Soc. Am.* **37**, 409-412. New method of measuring reverberation time.

[4] S. Sato and Y. Ando 1999 On the apparent source width (ASW) for bandpass noise related to the IACC and the width of the interaural crosscorrelation function (W_{IACC}). *Proc. 137th Meeting Acoust. Soc. Am., 2nd EAA, 25th DAGA* (Berlin).

[5] Y. Ando, H. Sakai and S. Sato 1999 Fundamental subjective attributes of sound fields based on the model of auditory-brain system. *In Computational Acoustics in Architecture*, WIT Press, Southampton, Ed. Sendra, J. J., Chap. 4, 63-99.

[6] Y. Katsuki, T. Sumi, H. Uchiyama and T. Watanabe 1958 *J. Neurophysiol.* **21**, 569-588. Electro responses of auditory neurons in cat to sound stimulation.

[7] N. Y. –S. Kiang 1965 *Discharge Pattern of Single Fibers in the Cat's Auditory Nerve.* MIT Press, Cambridge, MA.

[8] Y. Ando, T. Okano and Y. Takezoe 1989 *J. Acoust. Soc. Am.* **86**, 644-649. The running autocorrelation function of different music signals relating to preferred temporal parameters of sound fields.

[9] Y. Ando 1983 *J. Acoust. Soc. Am.* **74**, 873-887. Calculation of subjective preference at each seat in a concert hall.

[10] Y. Ando 2001 *J. Sound and Vib.* **241**, 3-18. A theory of primary sensations and spatial sensations measuring environmental noise.

Chapter 2

[1] Y. Ando 1998 *Architectural Acoustics, Blending Sound Sources, Sound Fields, and Listeners*, AIP press / Springer-Verlag, New York.

[2] Y. Ando 1983 *J. Acoust. Soc. Am.* **74**, 873-887. Calculation of subjective preference at each seat in a concert hall.

[3] Y. Ando 1992 *Acustica* **76**, 292-296. Evoked potentials relating to the subjective preference of sound fields.

[4] Y. Ando and C. Chen 1996 *J. Archit. Plann. Environ. Eng. AIJ.* **488**, 67-73. On the analysis of autocorrelation function of alpha-waves on the left and right cerebral hemispheres in relation to the delay time of single sound reflection.

[5] C. Chen and Y. Ando 1996 *J. Archit. Plann. Environ. Eng. AIJ.* **489**, 73-80. On the relationship between the autocorrelation function of the alpha-waves on the left- and right cerebral hemispheres and subjective preference for the reverberation time of music sound field.

[6] Y. Ando, T. Okano, and Y. Takezoe 1989 *J. Acoust. Soc. Am.* **86**, 644-649. The running autocorrelation function of different music signals relating to preferred temporal parameters of sound fields.

[7] P. Fraisse 1982 *The Psychology and Music*, edited by D. Deutsch (Academic, Orlando, FL), Chap. 6, 149-180. Rhythm and tempo.

[8] L.L. Thurstone 1927 *Psychol. Rev.* **34**, 273-289. A Law of Comparative Judgement.

[9] F. Mostellor 1951 *Psychometrika* **16**, 207-218. Remarks on the Method of Paired Comparisons: III. A Test of Significance for Paired Comparisons When Equal Standard Deviations and Equal Correlations are Assumed.

[10] H.H. Jasper 1958 *Electroencephalogr. Clin. Neurophysiol.* **10**, 371-375. The ten twenty electrode system of the international federation.

Chapter 3

[1] Y. Ando 2000 *J. Sound Vib.* **241**, 3-18. A theory of primary sensations measuring environmental noise.

[2] Y. Ando 1998 *Architectural Acoustics, Blending Sound Sources, Sound Fields, and Listeners*, AIP press / Springer-Verlag, New York.

[3] Y. Ando, T. Okano and Y. Takezoe 1989 *J. Acoust. Soc. Am.* **86**, 644-649. The running autocorrelation function of different music signals relating to preferred temporal parameters of sound fields.

[4] Y. Ando 1983 *J. Acoust. Soc. Am.* **74**, 873-887. Calculation of subjective preference at each seat in a concert hall.

[5] Y. Ando 1977 *J. Acoust. Soc. Am.* **62**, 1436-1441. Subjective preference in relation to objective parameters of music sound fields with a single echo.

[6] K. Fujii, Y. Soeta and Y. Ando 2000 *J. Sound and Vib.* **241**, 69-78. Acoustical

properties of aircraft noise measured by temporal and spatial factors.

Chapter 4

[1] Y. Ando, Y. Nakane and J. Egawa 1975 *J. Sound and Vib.* **43**, 683-691. Effects of aircraft noise on the mental work of pupils.

[2] Y. Ando and S. H. Kang 1987 *Acustica*, **64**, 110-116. A study on the differential effects of sound stimuli on performing left - and right - hemispheric tasks.

[3] Y. Ando 1988 *J. Sound and Vib.*, **127**, 411-417. Effects of daily noise on fetuses and cerebral hemisphere specialization in children.

[4] Y. Ando 1998 *Architectural Acoustics, Blending Sound Sources, Sound Fields, and Listeners*, AIP press / Springer-Verlag, New York.

[5] Y. Ando 2001 *J. Sound and Vib.* **241**, 129-140. Differential effects of noise and music signals on the behavior of children.

[6] Y. Ando 2001 *J. Sound and Vib.* **241**, 3-18. A theory of primary sensations and spatial sensations measuring environmental noise.

[7] Y. Ando 1992 *Acustica*, **76**, 292-296. Evoked potentials relating to the subjective preference of sound fields.

Chapter 5

[1] Y. Ando 1998 *Architectural Acoustics, Blending Sound Sources, Sound Fields, and Listeners*, AIP press / Springer-Verlag, New York.

[2] Y. Ando 1983 *J. Acoust. Soc. Am.* **74**, 873-887. Calculation of subjective preference

at each seat in a concert hall.

[3] Y. Ando, T. Okano, and Y. Takezoe 1989 *J. Acoust. Soc. Am.* **86**, 644-649. The running autocorrelation function of different music signals relating to preferred temporal parameters of sound fields.

[4] Y. Ando and C. Chen 1996 *J. Archit. Plann. Environ. Eng. AIJ.* **488**, 67-73. On the analysis of autocorrelation function of alpha-waves on the left and right cerebral hemispheres in relation to the delay time of single sound reflection.

[5] C. Chen and Y. Ando 1996 *J. Archit. Plann. Environ. Eng. AIJ.* **489**, 73-80. On the relationship between the autocorrelation function of the alpha-waves on the left- and right cerebral hemispheres and subjective preference for the reverberation time of music sound field.

[6] Y. Ando 2001 *Journal of Sound and Vibration* **241**, 3-18. A theory of primary sensations and spatial sensations measuring environmental noise.

[7] Y. Ando, S. Sato and H, Sakai 1999 in Fundamental subjective attributes of sound fields based on the model of auditory-brain system, J. J. Sendra editor, Computational acoustics in architecture. Southampton: WIT, chapter 4.

[8] Y. Ando 1977 *J. Acoust. Soc. Am.* **62**, 1436-1441. Subjective preference in relation to objective parameters of music sound fields with a single echo.

[9] T. D. Griffiths, C. J. Bench and R. S. J. Frackowiak 1994 *Current Bioloby* **4**, 892-895. Human cortical areas selectively activated by apparent sound movement.

[10] F. Baumgart, B. Gaschler-Markefski, M. G Woldorff, H. Heinze and H. Scheich 1999 *Nature* (London) **400**, 724-726. A movement-sensitive area in auditory cortex.

[11]Fraisse, P. 1982 *Rhythm and tempo. In the Psychology of Music.* (Ed. Deutsch, D.). Ed., Academic Press, Orlando, Fl. Chapter 6.

[12] K. Mouri, K. Akiyama, and Y. Ando 2001 *J. Sound and Vib.* **241**, 87-95. Preliminary study on recommended time duration of source signals to be analyzed, in relation to its effective duration of the autocorrelation function.

[13] L. Rayleigh 1907 *Phil. Mag.* **13**, 214-232. On our perception of sound direction.

[14] E. A. Macpherson and J. C. Middlebrooks 2002 *J. Acoust. Soc. Am.* **111**, 2219-2236. Listener weighting of cues for lateral angle: The duplex theory of sound localization revisited.

[15] W. E. Feddersen, T. T. Sandel, D. C. Tears, and L. A. Jeffress 1957 *J. Acoust. Soc. Am.* **29**, 988-991. Localization of high-frequency tones.

[16] J. F. Culling and Q. Summerfield 1998 *J. Acoust. Soc. Am.* **103**, 3540-3553. Measurements of the binaural temporal window using a detecting task.

[17] D. W. Chandler and D. W. Grantham 1992 *J. Acoust. Soc. Am.* **91**, 1624-1636. Minimum audible movement angle in the horizontal plane as a function of stimulus frequency and bandwidth, source azimuth, and velocity.

8. List of publications

Full papers

Chapter 2

Mouri, K., Akiyama, K. and Ando, Y. 2000 J. Sound and Vib., 232, 139-147. Relationship between subjective preference and a-brain wave in relation to the initial time delay gap with vocal music.

Chapter 3

Mouri, K., Akiyama, K. and Ando, Y. 2001 J. Sound and Vib. 241, 87-95. Preliminary study on recommended time duration of source signals to be analyzed, in relation to its effective duration of autocorrelation function.

Chapter 4

Mouri, K., Akiyama, K. and Ando, Y. 2001 J. Sound and Vib. 241, 141-145. Effects of telephone ring on two mental tasks relative to an office.

Chapter 5

Mouri, K., Fujii, K., Shimokura, R. and Ando, Y. The role of the interaural cross correlation function relating to the moving sound image for the band noise (to be published).

Proceedings of the International Congress

[1] Mouri, K and Ando, Y., On the sound environment for the right and left human hemispheric tasks., Proc. 3rd joint meeting of ASA and ASJ, Honolulu [J. Acoust. Soc.

Am.,100, 2787 (1996)].

[2] Mouri, K and Ando, Y., The relationship between subjective preference for sound fields and brain activity with vocal music., Proc. 16th intern. Congr. Acoust., and 135th Meeting Acoust. Soc. Am., 1, 17-18 (1998).