Analyses of cortical continuous brain waves in relation to subjective preference of physical environments

陳, 炯堯

(Degree)
博士（工学）

(Date of Degree)
1997-09-30

(Date of Publication)
2009-07-29

(Resource Type)
doctoral thesis

(Report Number)
甲1710

(JaLCDOI)
https://doi.org/10.11501/3141053

(URL)
https://hdl.handle.net/20.500.14094/D1001710

ANALYSES OF CORTICAL CONTINUOUS BRAIN WAVES IN RELATION TO SUBJECTIVE PREFERENCE OF PHYSICAL ENVIRONMENTS

（物理環境の心理的プリファレンスに関連する頭皮上連続脳波の解析）

A Dissertation
Submitted to
The Graduate School of Science and Technology
Kobe University
Kobe, Japan

In the Partial Fulfillment
of the Requirements for the Degree of
Doctor of Engineering

CHIUNG YAO CHEN

September 1997

PREFACE

This dissertation is submitted, in partial fulfillment of the requirements for the Doctor of Philosophy degree, to the Graduate School of Science and Technology, Kobe University. Alpha rhythm is well known as the most classically neuropsychological attributes of subjective states and behavioral manifestations, and it varies noticeablely in the time properties of our surroundings. This report attempts to find the relationships between the subjective preference of time and an autocorrelation analysis in α-waves range in relation to the physical parameters.

At this opportunity, the author wishes to thank Professor Yoichi Ando of Kobe University for his considerable guidance and encouragement, Professor Shinzo Kitamura of Kobe University for his considerable encouragement.

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

ABSTRACT

The living environment is composed of elements involving spatial and temporal factors. The spatial standards were frequently employed to design as knowledge, but the temporal standard was not clear, and there was few theory formally adopted pertinently. Nevertheless, the temporal factors are obviously concerned with activity in the left cerebral hemisphere, in accordance with physical environment changes. Here, it was objectively led this phenomenon further. For sound fields, four independent physical factors were prevailing for designing a sound field: (1) the initial time delay gap between the direct sound and the first reflection, Δt_1; (2) the subsequence reverberation time, T_{sub} ; (3) the level of listening, LL; and (4) the magnitude of interaural cross-correlation (IACC). In particular, the first two factors have been composed of a standard of time. The subjective preference theory was effectively applied for the planning of a few music halls. As far as the temporal factors are concerned, the preference of sound fields can be calculated by autocorrelation function of sound source signal together with such temporal factors. But it is weakness for subjective evaluation in general living environments entirely obtained by questionnaire using “language”. Therefore, a method for measuring a human being’s brain responses to external sound stimuli was arranged. The aim of present study was to identify the relationship between the subjective preference and the brain responses corresponding to the temporal variation. The method applied here is to analyze the autocorrelation function of continuous brain waves (CBW) in the α-wave range and extend this relationship for a visual environment that trying to approach for all conditions.

Up to present, CBW were reported by the wave type or the frequency variation, it is inadequacy to observe following a variation of temporal occasion. The “effective duration” (τ_e) was defined by the effective gap of the initial deduction (0.1 envelope) of the autocorrelation function (ACF) in the α-wave range; it involves a 2.5 s linear integral sum to correspond well to the stimulation by considering “psychological present”.

Chapter I states an important theory of subjective judgement, a theory that gives us a concept of the relationship between subjective preference and the autocorrelation function of brain waves.

Chapter II optimizes a stimulation system (paired-comparison system) and the analyses

of ACF of brain waves in the α-wave range by changing the Δt_1 of a music sound field (Motif B: Arnold's Sinfornietta, Opus 48) to 35 ms and 245 ms. Results show that the effective duration of ACF (τ_e) of CBW in the α-wave range correlates well to the subjective preference in a 2.5 s segment corresponding to the "psychological present". Furthermore, the values of τ_e in the α-wave range correspond efficiently to the subjective preference and prolongs when the preference score increases. The EEG channel T3 is a forcible recording for detecting the temporal variation in brain by comparing with T4.

Chapter III extends the relationship between subjective preference and the values of τ_e in the α-wave range to examine by changing T_{sub}, from 0.2 s to 3.2 s of 7 logarithm grade in a music sound field (Motif B). Results show the preferred T_{sub} are centered on 1.2 s. Thus, CBW were recorded by represented T_{sub} from 0.2 to 1.2 s and 1.2 to 6.4 s. It's remarkable that τ_e, ACF in the α-wave range corresponds well to the scale values (SV) of subjective preference. The significantly ($p < 0.01$) longer τ_e of α-waves were found as the SVs of preference increased in the range of 0.2 to 1.2 s. Large individual differences may be reflected in the left hemisphere, so the correlation between SV and τ_e is closer ($r = 0.70$, $p < 0.05$) in the left hemisphere (T3) than those in the right (T4) in the range of 1.2 to 6.4 s.

Chapter IV has successfully applied the findings in chapters II and III to the simple time cognition i.e., auditory tempo. The values of τ_e in the α-wave range is an efficient and consistent objective parameter to observe the preference. The method is to change the subjective tempo by period from 300 to 1,000 ms in 6 logarithm level by the noise burst (10 ms). Results also show a closer correlation ($r = 0.80$, $p < 0.01$) between SV and τ_e in the left hemisphere (T3) than in the right (T4) in the range of 550 to 1,000 ms.

Chapter V also examines the subjective preference of visual tempo relative to the values of τ_e in the α-wave range. The correlation was highly ($r = 0.94$, $p < 0.01$) obtained in the left hemisphere (T5) than that in right by varied periods from 0.2 to 3.2 s. Not only was the correlation found to be consistent, such the hemispheric specialization was also reconfirmed by analyzing the cross-correlation function between electrodes on the left and right channels.

Chapter VI reviews the cerebral hemispheric specialization theory by cross-correlation analyses. The data employed in chapters II and III were used for calculations. The method was interpreted in Chapter V. The maximum values of the cross-correlation function between left and right EEG channels reveals that the brain has a specialized management process for temporal information. It also supports the auditory pathway model proposed by Ando.

Chapter VII summarized the results from chapter II to VI, and tackled some interesting problems in present study. They give us the conclusion of the present study :1). Cerebral hemispheric dominance hypothses and the subjective judgement processes model in the auditory path (**Fig. 1.5**) have been confirmed by the effective duration of ACF (τ_e) and the maximum values of CCF in the α-wave range. 2). The value of τ_e in the α-wave range in a 2.5 s linear sum of ACF prolongs when the scale value of subjective preference increasing in case that physical factors changed in environments. 3). The value of τ_e, ACF in the α-wave range may function as the scale values of subjective preference pertaining to individual differences in changing physical factors.

In case that changed the IACC for binaural hearing that is a spatial standard of a sound field was further discussed by the values of τ_e of α-wave and the subjective preference.

Finally, the relationship between the subjective preference and continuous brain waves in the α-wave range is identified by the autocorrelation analyses. The values of τ_e , ACF in the α-wave range correlate well to the scale values of subjective preference in case that changing physical factors. It is also confirmed that correlation analyses may give us a tool for evaluating the preference of other physical environments around us.

ACKNOWLEDGMENTS

I would express my thanks to the many people who have, in various ways, helped me to attain my objective of preparing this dessertation. I am indebted to **Professor Yoichi Ando** for his constant supervision to complete this research. Along the way, I have received important understanding and encouragement from **Professor Shinzo Kitamura**.

Special thanks are due to the many colleagues for their participancy in the experiments of the subjective judgements and the brain waves recordings. Also, I want to express my gratitude for a small group of people who worked closely with me at Artificial Intelligence Laboratory, Graduate School of Science and Technology, Kobe University. Special thanks are due to Dr. Tatsumi Nakajima of Takenaka Corp., Dr. Junji Korenaga of Kajima Corp., Yasutaka Ueda of Hazama Corp., Dr. Singh Prabhat Kumar and Dr. I Gde Nyoman Merthayasa for their enjoyable and strengthening interaction. Also, my thanks to Mr. Hiroyuki Sakai, Shinichi Sato, Takuji Sumioka, Kiminori Mouri, Tetsuichi Shoda, Junko Atagi and Kenj Fujiii, the members of the Seminar. And, I am particularly grateful to Mr. Akihico Tarutani, Kazuki Nishio, Hiroshi Ryugo and Yoshiharu Soeta, as my research team.

Due to the Great Eartquake of Kobe on 17 January 1995, this research was postpone at an append experiment of my first paper. Therefore, it takes 6 years allow me to complete this study. I would like to express my regard to the Scholarship Sugehara of Kobe city government for their financial support for a period of 5.5 years and since April 1993 up to September 1997.

Finally, I wish to thank my wife, **Hsiupao**, my elder daughters **Yenyue**, my younger daughter **Yenjing** for their support, patience, love, and understanding. Also I would like to express my sincerely thank for my Father, Mother and my sister.

TABLE OF CONTENTS

CHAPTER I INTRODUCTION

1.1. Preface ---------- 1
1.2. The Subjective Preference for the Music sound Field ---------- 1
1.3. Previous Investigation on Brain Waves ---------- 9
1.4. Purpose of This Study ---------- 15
1.5 Summary ---------- 15

CHAPTER II AUTOCORRELATION FUNCTION OF α-WAVES RELATIVE TO THE DELAY TIME OF SINGLE SOUND REFLECTION OF MUSIC SOUND FIELD

2.1. Introduction ---------- 16
2.2. Random processing of continuous brain waves and effective duration of ACF 17
2.3. Psychological present ---------- 21
2.4. Experiment ---------- 22
2.5. Results ---------- 24
2.6. Conclusions and discussion ---------- 27
2.7. Summary ---------- 28

CHAPTER III AUTOCORRELATION FUNCTION OF α-WAVES RELATIVE TO THE REVERBERATION TIME OF MUSIC SOUND FIELD

3.1. Introduction ---------- 29
3.2. Experiment ---------- 30
3.3. Results ---------- 34
3.4. Conclusions ---------- 37
3.5. Summary ---------- 40

CHAPTER IV AUTOCORRELATION FUNCTION OF α-WAVES AND SUBJECTIVE

PREFERENCE RESPONDING TO THE NOISE-BURST TEMPO

4.1. Introduction ---------- 42
4.2. Experiment ---------- 44
4.3. Results ---------- 47
4.4. Conclusions ---------- 49
4.5. Summary ---------- 52

CHAPTER V AUTOCORRELATION FUNCTION OF α-WAVES AND SUBJECTIVE PREFERENCE RESPONDING TO THE VISUAL TEMPO

5.1. Introduction ---------- 53
5.2. Methodology ---------- 55
5.3. Results ---------- 59
5.4. Conclusions and discussion ---------- 62
5.5. Summary ---------- 62

CHAPTER VI DYNAMIC ANALYSES OF BRAIN WAVES : CROSS-CORRELATION FUNCTION OF α-WAVES BETWEEN EEG CHANNELS

6.1. Introduction ---------- 66
6.2 Methodology ---------- 67
6.3. Results ---------- 68
6.4. Conclusions ---------- 68
6.5. Summary ---------- 69

CHAPTER VII SUMMARY AND CONCLUSIONS

7.1. Summary and conclusions of the studies ---------- 74
7.2. Further Problems ---------- 75

REFERENCES -- 77

APPENDIX -- 81

LIST OF PUBLICATIONS --- 92

CHAPTER I

INTRODUCTION

1. 1 PREFACE

"Ma" is a Japanese character that means space between things, and it is used to refer to the intervals or deliberate pauses in speech, gesture, or action. In architecture, ma refers to spacing or timing that may frame or pace a work, enhancing the aesthetic expression. Studies of ma in human time perception may reveal the coding in the central nervous system and specialization in the processing of temporal information management.

The aim of this study is to give an integrative approach to time sense and to focus on the relationship between the subjective preference and the responses of the human brain, trying to link subjective evaluation in a concert hall to common environmental preference by autocorrelation analysis of the α-wave range of cortical continuous brain waves. First, auditory clues in concert hall acoustics are applied and the correlation between preference evaluation and brain waves is clarified. To greatly improve this, a simple time cognition for auditory or visual tempo was used to confirm the consistency of the knowledge in a sound field. Finally, to clarify the temporal charactertistics of lateral dominance, the dynamic flow of signals between left and right hemispheres is analyzed by a cross-correlation method.

1. 2 SUBJECTIVE PREFERENCE FOR A MUSIC SOUND FIELD

A great deal of subjective judgement of simulated sound fields has been done to evaluate sound field preferences by changing four independent factors [1]:

(i) Listening level, LL;
(ii) Delay time between the first reflection and the direct sound, Δt_1;
(iii) Subsequence reverberation time, T_{sub}, and
(iv) Magnitude of interaural cross correlation, IACC.

Factors (ii) and (iii) are composed of the standard of time, since they express the timing processes of arriving potential at the ears from the source. The factor IACC is associated with the arrival direction of the sound signal in the case of binaural hearing, thus it has been termed as a spatial standard. The sound signals processing in the auditory mechanism also depends on the model of the auditory path ways, with the autocorrelation analyses as a temporal sound signal processor and the interaural cross-correlation as a spatial signal processor, as proposed by Ando [1]. According to this model, the power density spectra in the neural activities in both auditory pathways are stochastically transformed into the autocorrelation functions in the left and right cerebral hemispheres, respectively. These transformations occur at the superior olivary complex in the lateral lemniscus, and it is supposed that they are performed in a manner equivalent to the Fourier cosine transform.

1. 2. 1 ACF analysis of sound fields

To analyze a sound field, Ando [2] considers a single sound source signal p(t) located at an arbitrary point in a room (**Fig. 1.1**). The sound signal at both ears heard by one listener also at an arbitrary point in the same room is expressed by:

$$f_{L,R}(t) = \sum_n p(t)*A_n \omega_n(t-\Delta t_n)*h_{nL,R}(t), \tag{1.1}$$

where

$\omega_n(t)$: the impulse responses of the reflecting boundaries.

A_n : the amplitude of the nth echo relative to the direct sound, inversely proportional to r, A_0 being unity,

Δt_n : the delay time of the nth echo relative to the direct sound, Δt_0 being zero, and

$h_{nL,R}(t)$: the pressure impulse responses between the sound source and the left and the right ear canal entrances. The asterisk denotes convolution.

All independent objective parameters included in Eq. 1.1 may be reduced to the autocorrelation function for a source signal p(t) as the following (monoaural criterion):

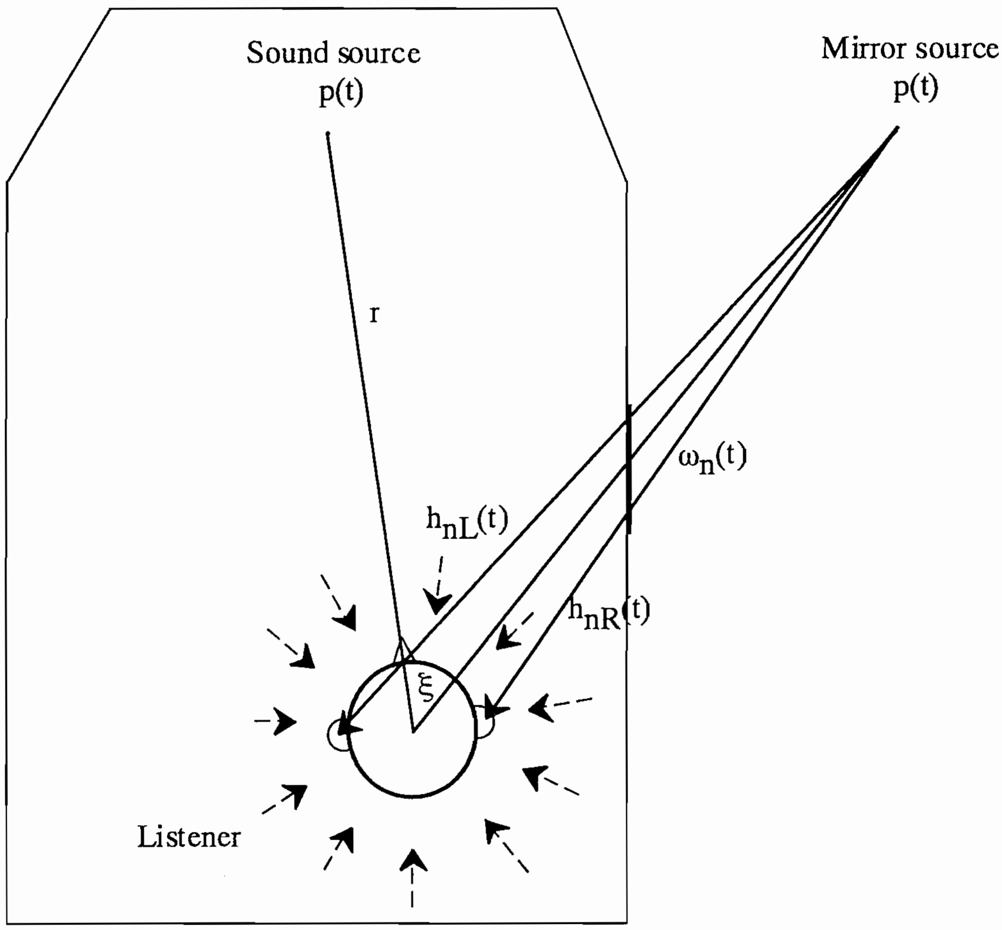


Fig. 1.1 The listener in a sound field was considered at an arbitrary position at a distance of r from sound source p(t).

$$\Phi_p(\tau) = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{+T} p'(t)p'(t+\tau)dt, \qquad (1.2)$$

where $p(t)' = p(t) * h(t)$,

h(t) : The filter of the ear expressed in the time domain, conveniently expressed by an A-weighting filter that corresponds to ear sensitivity.

And, when two sets of the head related impulse responses for two ears (binaural criterion),the normalized interaural cross-correlation is expressed by

$$\phi_{LR}^{(n)}(\tau) = \frac{\sum A_n^2 \Phi_{LR}^{(n)}(\tau)}{\sqrt{\sum A_n^2 \Phi_{LL}^{(n)}(0) \sum A_n^2 \Phi_{RR}^{(n)}(0)}}, \tag{1.3}$$

where $\Phi_{LL}^{(n)}(0)$ and $\Phi_{RR}^{(n)}(0)$ are autocorrelation functions (at $\tau = 0$) of the nth echo at the eardrums. The magnitude of interaural cross correlation (IACC) is defined by

$$IACC = |\phi_{LR}(\tau)|_{max} \quad \text{for } |\tau| < 1 \text{ ms}. \tag{1.4}$$

Using Eq.1.4, the sound fields in a concert hall may be simulated by a system as shown in **Fig. 1.2**. A sound source is fed through an A/D converter into a computer whose program provides the amplitude and the delay of the first two reflections ($n = 1, 2$) and the subsequence reverberation ($n \geq 3$) relative to the direct sound. The notation "Rev." in the figure states for reverberation. Discrete time delays of Δt_1, Δt_2, Δt_3 were introduced and signals were then fed to the loudsperkers. The IACC was adjusted by varying the location of the loudspeakers around the listener's head.

1. 2. 2 Subjective preference of paired-comparison

In this study, the scale values of subjective preference for a sound field were completely calculated by Thrstone's case V model [4] and mentioned above. This sensory scale is a good basis for the paired-comparison method. Response to the stimuli is easy and instant even though subjects do not have concert experiences.

The stimuli R_j and R_k ($j,k=1,2,\cdots,N$) were independently presented N times to each subject, and the probability $P(R_j > R_k)$ that stimulus R_j was judged greater than stimulus R_k could be thought of as a monotonically increasing function of discriminating differences along the linear scale S, noted by $S_{jk} = S_j - S_k$. The fuction of P could be expressed using S_j and S_k as below

$$P(R_j > R_k) = F(S_j - S_k), \tag{1.5}$$

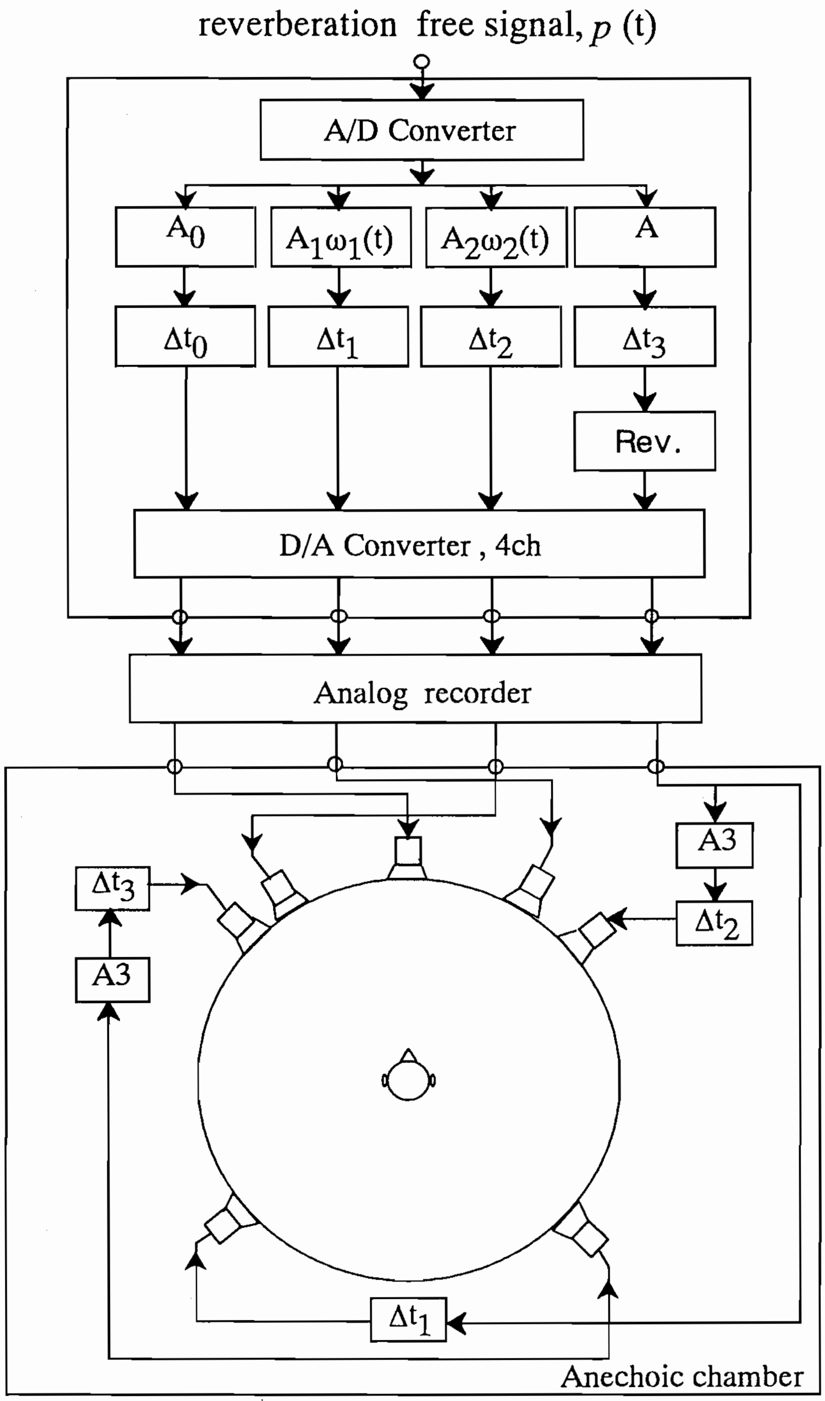


Fig. 1.2 A simulation system of a sound field arranged by Ando[1], which composed of adigital sound processor and a simulative indoors sound field, the direct and thereflectionswere separately represented by loudspeakers. Direction of subsequentreverberations wereplaced at ±(55° to 22°) to request to keep off a small IACC.

Note: Figure was arranged by Ando and Imamura[3].

where F is the cumulative distribution function.

Thurstone's model employs a normal cumulative distribution with a standard deviation in the judgement process, $\sigma_{jk} = (\sigma_j^2+\sigma_k^2-2\rho_{jk}\sigma_j\sigma_k)^{1/2}$, where ρ_{jk} is the coefficient of correlation between S_j and S_k, so the probability P ($R_j > R_k$) is given by

$$P_{jk} = P_r\{S_{jk}>0\} = \frac{1}{\sqrt{2\pi}\,\delta_{jk}} \cdot \int_0^{\infty} \exp\left\{-\frac{\left[S_{jk}-(\overline{S}_j-\overline{S}_k)\right]^2}{2\delta_{jk}}\right\} dS_{jk}, \qquad (1.6)$$

where $\overline{S}_j-\overline{S}_k$ is the mean value of S_{jk}.
Furthermore, the cumulative distribution function of the standard normal distribution is obtained by

$$P_{jk} = \frac{1}{\sqrt{2\pi}} \cdot \int_{Z_{jk}}^{\infty} \exp\left\{-\frac{z^2}{2}\right\} dz, \qquad (1.7)$$

where $Z_{jk} = -(S_j - S_k) / \sigma_{jk}$, then $(S_j - S_k) = Z_{jk} (\sigma_j^2+\sigma_k^2-2\rho_{jk}\sigma_j\sigma_k)^{1/2}$.

Thurstone's case V assumed that the judgement process has a constant $\rho_{jk} > 0$, and σ_{jk} is also constant dispite the differences between R_j and R_k, so

$$(\overline{S}_j-\overline{S}_k) = \sqrt{2(1-\rho)}\,\sigma Z_{jk}. \qquad (1.8)$$

Where the 0 and units along the linear scale S was assumed as

$$\sum_{j=1}^{n} \overline{S}_j = 0 \qquad (1.9)$$

and

$$\sqrt{2(1-\rho)}\,\sigma = 1 \qquad (1.10)$$

Thus, $(S_j - S_k) = Z_{jk}$ offers a simple method for calculating the scale values of subjective preference.

1. 2. 3 Subjective preference of a sound field

The sound field is evaluated by four factors using Thurston's preference test and computer simulation. They clearly lead to comprehensive criteria for optimal concert halls. The information in the subjectively preferred sound qualities are arranged.

A. Listening level

The preferred listening level depends on the particular music being preformed. The preferred level of motif B (Sinfonietta by Anorld[5]), systematically employed in this study was 79 ~ 80 dBA.

B. Delay time between the first reflection and the direct sound

A correlation between the process of a sound signal's transformation to the eardrums and the autocorrelation function has been discovered as discussed in the Section of 1. 2. 1. This relationship is clearly confirmed by the preferred delay time

$$[\Delta t_1]_p \approx (1 - \log_{10}A)\tau_{e\ min}. \tag{1.11}$$

where the total pressure amplitude of reflections is definded by

$$A = (A_1{}^2 + A_2{}^2 + A_3{}^2 + \cdots + A_N{}^2)^{1/2}. \tag{1.12}$$

and $\tau_{e\ min}$ is the minimum value of effective duration of running ACF (see Section of 2.2) of sound source signal, defined by the delay at which the envelope of the normalized ACF becomes 0.1. For a single reflection ($A_0 = A_1 = 1$), the preferred delay was about 32 ms for Motif B.

C. Subsequence reverberation time

Thepreferred subsequence reverberation time is simply expressed by

$$[T_{sub}]p \approx 23\ \tau_{e\ min}. \tag{1.13}$$

D. Magnitude of interaural cross correlation

People prefer their left and right ears to receive dissimilar signals. This is the most effective way to obtain a small IACC by sound arriving direction between the reflections and the direct (see Section of 1. 2. 1). Ando[1] arranged that the early reflections arrive at the listener within a certain range of angles from the frontal direction ±(55° to 20°), to get the most dissimilarity between the signals at each ear. It is clear that the sound arriving from the median plane $\xi = 0°$ makes the IACC greatest, and $\xi = 90°$ in the horizontal plane is a similar detour path to the ears cannot decrease the IACC effectively. The most effective angles for the frequency of 1 kHz and 2 kHz are about ± 55°and ± 36°, respectively.

1. 2. 4 Independence of subjective attributes

The independence of the four factors in music sound fields are identified by analysis of variance (ANOVA) of the scale values obtained from each sound field for an individual subject. Thus, we can add the scale values as below:

$$\begin{aligned} S &= g(x_1) + g(x_2) + g(x_3) + g(x_4) \\ &= S_1 + S_2 + S_3 + S_4. \end{aligned} \tag{1.14}$$

The scale values were obtained by paired-comparison. Ando [1] arranged them by using different music Motif, and gave the following formula for the scale value of subjective preference:

$$S_i \approx \alpha_i |x_i|^{3/2} \tag{1.15}$$

where α function the different series of sound field in terms of the cube of the square root of objective factor. If they are given by an individual subject, α expresses the individual difference. The four objective factors have different measures as below:

$$\begin{aligned} x_1 &= 20 \log (P/[P]_p) \quad (\text{dB}) \\ x_2 &= \log(\Delta t_1 / [\Delta t_1]_p) \\ x_3 &= \log(T_{sub} / [T_{sub}]_p) \\ x4 &= \text{IACC} \end{aligned} \tag{1.16}$$

where P is the sound pressure level at the seat and $[P]_p$ is the preferred sound pressure at a particular seat position.

1. 3 PREVIOUS INVESTIGATION OF BRAIN WAVES

1. 3. 1 Previous reports on the auditory evoked potential

The previous section discussed four independent physical factors of the music sound field in a concert hall. This section describes a few findings about these four factors, which interpret the sound processes occurring in the auditory pathways. They are observed by using auditory evoked potential (AEP) method. It is possible to design a concert hall according to this information, if there is enough, and it is possible to modify the impulse responses derived from the auditory central nervous system in accordance with the subjective preference. Furthermore, these four factor comprise the standards of time and space, a manangement specialization theory for the cerebral hemispheres was proposed.

For the cerebral physiology corresponding to a sound environment, "auditory evoked potential (AEP)" has been used frequently. Electric potential is caused by the stimuli of voice, music, speech, tone pulse and so on. The sound signal is converted to an electric signal by cochlea. Before the electric signal arrives at the auditory cerebral cortex, the potential of the auditory conduction path can be recorded by the summation method over a short time range (0 ~ 400 ms) as illustrated in **Fig. 1.3**.

Morrell and Salamy [7] first recorded the slow vertex responses (SVR) with the AEP method on wide range scalp by 50 averaging. When they triggered a stimulus, the peak of the SVR wave always appears as a standard. The name "latency" refers to the time interval between triggering and peak. The potential difference between one peak to the next was named "amplitude" (**Fig. 1.3**). With the variation of these two standards, responses caused by stimulation were first investigated.

Ando [8] summarized all SVR data, and **Table 1.1** shows that the hemispheric dominances differed for different sound signals and acoustic factors of the sound field. It is remarkable that hemispheric dominance appeared only in the amplitude of SVR. Nevertheless, the latency of SVR significantly varied with respect to the subjcetive preference between left and right hemispheres (**Fig. 1.4**). It well known that the left hemisphere is mainly associated with speech and time sequential indentifications and the right hemisphere is concerned with nonverbal and spatial indentifications (Sperry [9]).

1. 3. 2 Previous reports on continuous cortical brain waves

The AEP research can not be applied to a long physical quantitative variation above

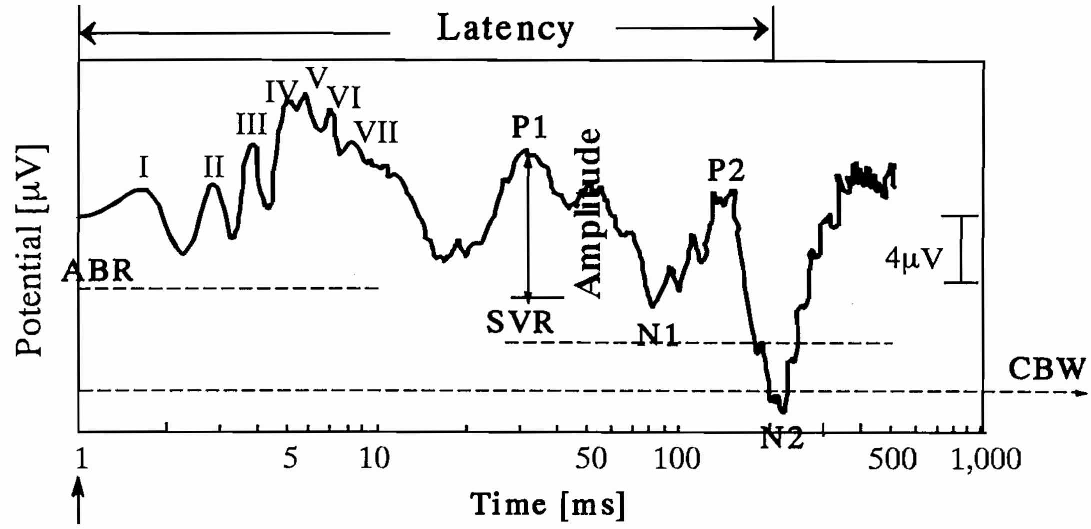


Fig. 1.3 The auditory evoked potential (AEP) is a method of gathering the averaging wave form of electroencepalography (EEG) in a section of beginning at stimulus onset. The averaging frequency is decided by the magnitude of evoked potential, for example, SVR needs about 50 times averaged, the ABR is need more, the CBW can be recorded through originality.

Note: Figure was arranged by Ichikawa [6].

ABR: auditory brainstem response, SVR: slow vertex response, CBW: continuous brain waves.

Table 1.1 Hemispheric differences with respect to the amplitude of the early slow vertexresponse (SVR), A (P1 -N1).

Note: The amplitude A (P1 -N1) is defined in **Fig. 1.2**.

Source signal	Parameter adjusted	A(P1 - N1)	Significat level
Speech (0.9 s)	SL	R > L	< 0.01
Speech (0.9 s)	Δt1	L > R	< 0.01
Speech vowel [a]	IACC	R > L	< 0.025
1/3-Octave band noise (500 Hz)	IACC	R > L	< 0.05

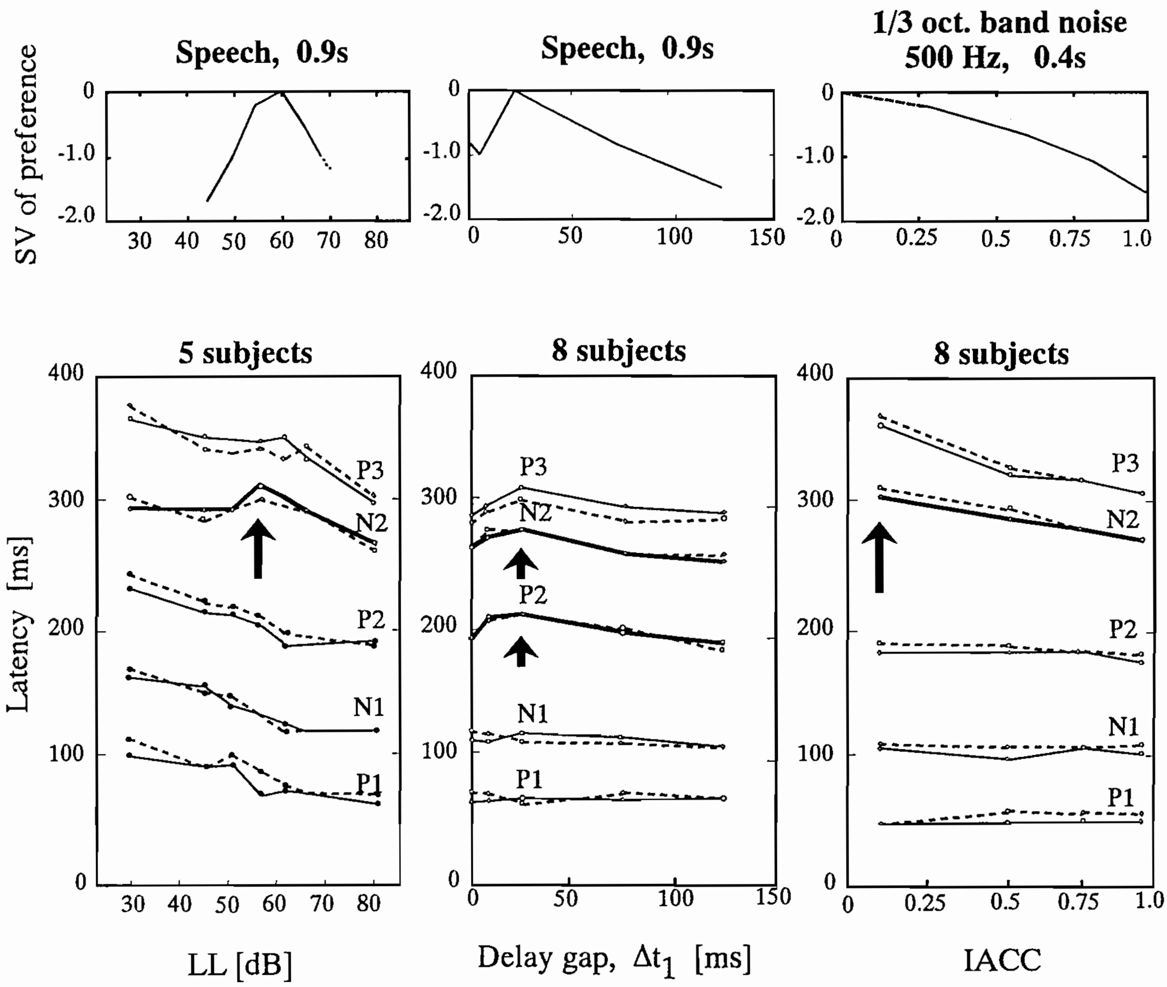


Fig. 1.4 Relationship between latencies of slow vertex response (SVR) and subjectivepreference for three objective parameters.
Note: Reference: Figure is arranged by Ando [8].
Left hemisphere —— Right hemisphere ·····

400 ms. But, for example, the preferred reverberation time in an opera house is longer than 2 s. Therefore, it is necessary to observe continuous brain waves (CBW) which represent perception of the longer charactertistics in a sound field.

In CBW research, there are plenty of problem relating to the psychological aspects of sensation, perception, attention, emotion, learning, intelligence, and personality, and they have been closely studied. Lindsley [10] concluded, with reliable psychological and neurophysiological data, that the outstanding parameter of the data is time. This is especially true for frequency, the alpha rhythm's (α-wave, 8 ~ 13 Hz) range varies during the range of behavioral states common to a normal adult. **Table 1.2** indicates the psychological states and their correlation with electroencepalography (EEG, representing electric activities of the whole brain), states of consciousness and behavior.

In recent years, electrophysiological researchers have found that each cortical area has a unique functional role. They can be investigated by International 10/20 placement system (see **APPENDIX A**) with average subjects. The largest difference in the balance of an EEG is the hemispheric difference during tasks which require verbal as opposed to spatial processing (reported by Davidson and Ehrlichman [11]).

Praetorius, Bodenstein and Creutzfeldt [12] proposed a statistical analysis law for continuous brain waves. They insisted the spectral analysis eliminates most of the information contained in its time structure and may thus underestimate relevant patterns at every moment.

Ando applied the independent acoustic standards classified by the autocorrelation analysis and the interaural cross correlation of the sound signals to design a sound field. He also gives a model consisting of the autocorrelation mechanisms and interaural cross-correlation mechanisms of the two auditory pathways, and the specialization of human cerebral hemispheres for processing temporal and spatial factors of a sound field. This model, shown in **Fig. 1.5,** is based on the subjective attributes and on the AEP research on responses to changes in acoustic factors. The sound source p(t) in this figure, is located at r_0 in a 3-dimensional space and a listener is sitting at r (defined by the location of the centre of the head), $h_{L,R}(r|r_0,t)$ being the impulse responses between r_0 and the left- and right ear-canal entrances. The impulse response of the external ear canal is $e_{L,R}(t)$ and that of the bone chain is $c_{L,R}(t)$. The velocities of the basilar membrane are expressd by $V_{L,R}(x,\omega)$, x being the position along the membrane. The action potential from the hair cells is conducted to the cochlear nuclei, the superior olivary complex (including the medial superior olive, the lateral superior olive, and the trapezoid body), and the higher levels of the cerebral cortex.

1.4 PURPOSE OF THIS STUDY

The analysis of ACF is a better way for time structure of continuous brain waves was asummed by following the auditory processing model proposed by Ando (**Fig. 1.5**). Alpha

Table 1.2 Arrangement of accumulated data from many study in a sense between thealpha rhythm and psychological and behavioral processing by Lindsley[10].

BEHAVIORAL CONTINUUMB	ELECTROENCEPHA-LOGRAM	STATE OF AWARENESS	BEHAVIORAL EFFICINCY
Strong. Excited Emotion (Fear) (Rage) (Anxiety)	Desynchronized: low to moderate amplitude; fast mixed frequencies.	Restricted awareness; divided attention diffuse, hazy; "Confusion"	Poor: (lack of control freezing-up, disorganized).
Alert Attentiveness	Partially synchronized: Mainly fast, low amplitude waves	Selective attention, but may vary or shift. "Concentration" anticipation, "set"	Good: (efficient, selective, quick, reactions) Organized for serial respones.
Relaxed Wakefulness	Synchronized: **Optimal alpha rhythm.**	Attention wanders - not forced. **Favors free association.**	Good: (routine reactions & creative thought).
Drowsiness	Reduced alpha & occasional low amplitude slow waves.	Borderline, partial awareness. Imagery & reverie. "Dream- like states".	Poor: (uncoordinated, sporadic, lacking sequential timing).
Light Sleep	Spindle bursts & slow waves (larger) Loss of alphas.	Markedly reduced consciousness (loss of consciousness) Dream state.	Absent
Deep Sleep	Large and very slow waves synchrony but on slow time base Random, irregular pattern.	Complete loss of awareness (no memory for stimulation or for dreams).	Absent
Coma	Isoelectric to irregular large slow waves.	Complete loss of consciousness little or no response to stimulation; amnesia.	Absent
Death	Isoelectric: Gradual and permanent disappearance of all electrical activity.	Complete loss of awareness as death ensues.	Absent

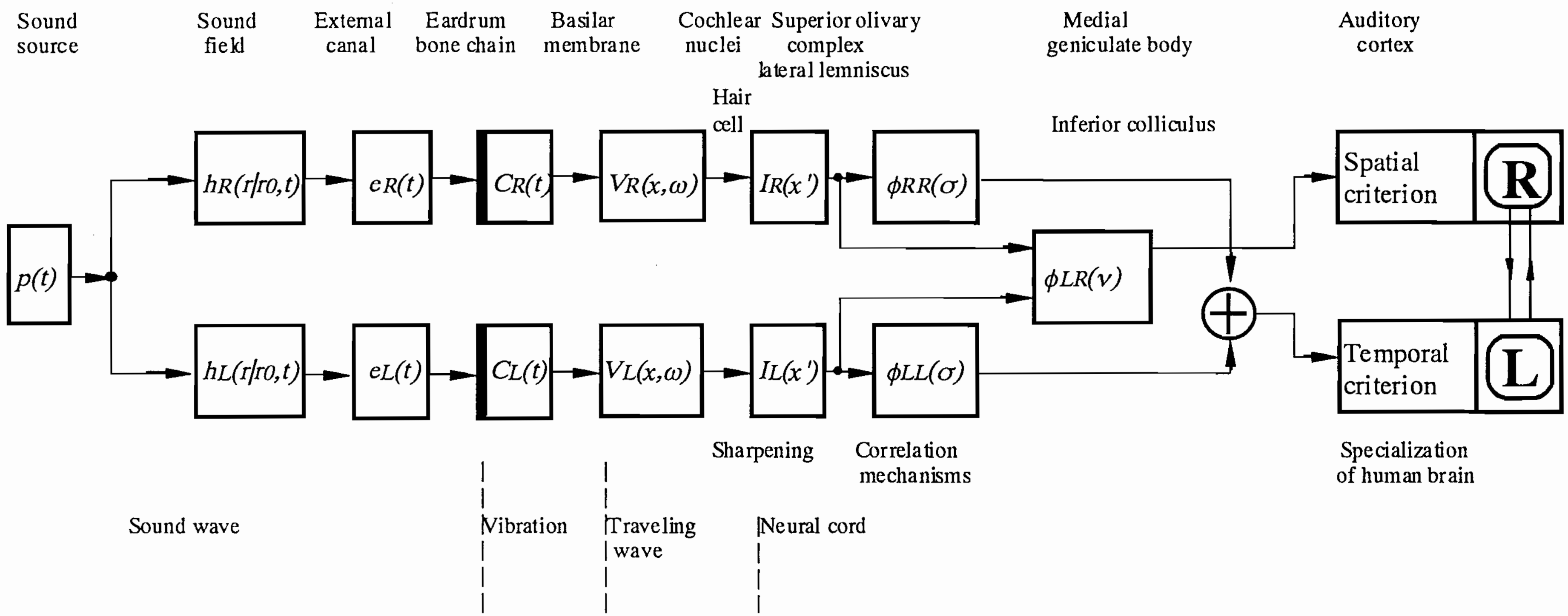


Fig. 1. 5 A model of the auditory-brain system (Ando, Y., 1985[1]).

wave range (8 ~ 13 Hz) may correspond well to the subjective preference. Four problems now arise : (I) the ACF analysis of brain waves has to detect a time structure in an instant, (II) the optimalized segments of ACF's analysis has to examine first for the stimulation, (III) the method of extracting the main features of CBW for classifying the subjective preference should be effective in average subjects, (IV) optimal recording placement of EEG for a reference of temporal information processing has to be under examination.

First, the optimal integration section has to decided for the stimuli. Then the relationship between them will extend to the other physical variations. Finally, a model for evaluating preference for environmental changes needs to be created.

1.5 SUMMARY

(1). A method of predicting subjective preference in a music sound field was proposed but outwith comprehensive application in normal environments.

(2). With regard to previous studies of auditory evoked potential, we considered a comparatively long recording of α-wave range of CBW may support a high correlation in relation to preference.

CHAPER II

AUTOCORRELATION FUNCTION OF α-WAVES RELATIVE TO THE DELAY TIME OF SINGLE SOUND REFLECTION OF MUSIC SOUND FIELD

2. 1 INTRODUCTION

2.1.1 Preface

The purpose of this chaper is to find a relationship between subjective preference and α-waves on the left and right cerebral hemispheres, an attempt is made here to analyze the autocorrelation function (ACF) of α-waves in relation to the delay time of single sound reflection (Δt_1). It is assumed that a similar repetitive feature of the α-wave range (8 ~ 13 Hz) in terms of the effective duration (τ_e) of ACF is related to pleasantness or subjective preference. The results show that the effective duration of ACF from the left hemisphere is significantly changed according to the preferred delay (35 ms) or the echo disturbance (245 ms) condition ($p < 0.01$), but not from the right hemisphere. These effects reveal the left hemisphere dominance when one of thetemporal factors of the sound field, the delay time of reflection, is changed ($p < 0.05$).

2.1.2 Conventional study on brain waves in relation to the subjective preference of single reflection of sound field

Ando, Kang and Morita [13], and Ando, Kang and Nagamatsu [14] investigated the auditory evoked potential in terms of the slow vertex response (SVR) obtained by the averaging technique (see Section 1.3.1), when a short signal - less than 0.9 s - was repeated alternatively in a manner similar to the paired-comparison tests. It is found that the N2-latencies of SVR are significantly prolonged in preferred conditions in both hemispheres. Also, the averaged amplitude at early stage of SVR, A(P1-N1), is significantly greater on the left hemisphere than in the right hemisphere when Δt_1 is varied in the pair.

2.1.3 The problems of the present study

According to the subjective judgement tests , the model of the auditory pathway concerned the temporal information processings are assumed as an autocorrelation management (see Section 1.3.2). Here, the analysis of ACF in α-waves range of continuous brain waves (CBW) is considered as a tool to evaluate the preference of time variation. However, there are some problems for ACF analyzing have to pay attention on:

(i) Optimal segmentation procedure to correspond with psychological response;

(ii) To characterize a time standard for preference evoluation in ACF fine strcuture;

(iii) The EEG channels and the temporal specialization on between cortical aeras.

2. 2 RANDOM PROCESSING OF CONTINUOUS BRAIN WAVES AND EFFECTIVE DURATION OF ACF

2.2.1 The effective duration of ACF in prediction of the most preferred Δt_1

As has been introducted in Section 1.3.2, the ACF analysis is supposed to be performed in the neural part of the auditory system within the time domain. In subjective judgements of sound field, the most preferred initial time delay gap between the direct sound and the first reflection have been found to be related to the ACF of the music source signal. Ando [15] has discussed a desired delay of ACF (τ_d) of source signal, which was obtained from subjective judgements and provided a function of the pressure amplitude of the echo to the delay times. As indecated in **Fig. 2.1**, the effective duration of ACF (τ_e) equals τ_d only when $A_1 = 1$. And this relationship can be simplely expressed by Eq. 1.11. Thetest sound sources were Motif A (by Gibbons, $\tau_e = 127$ ms), Motif B(by Arnold, $\tau_e = 35$ ms)[5], and a piece of female's voice of 4.5 s ($\tau_e = 12$ ms). Thus, The difinition of τ_e is the envelope of ACF becomes $0.1A_1$. And **Fig. 2.2** shows the relationship between the normalized scores of the sound field by adjusting the delay time in the range of 6 ~ 256 ms for the music of Motif A and B for 13 subjects.

2.2.2 The effective duration of ACF in α-waves range

To obtain a degree of similar repetitive features of the CBWs, the effective duration of ACF of the α-wave range in CBW, τ_e, was analyzed as a phenomenon of stationary random

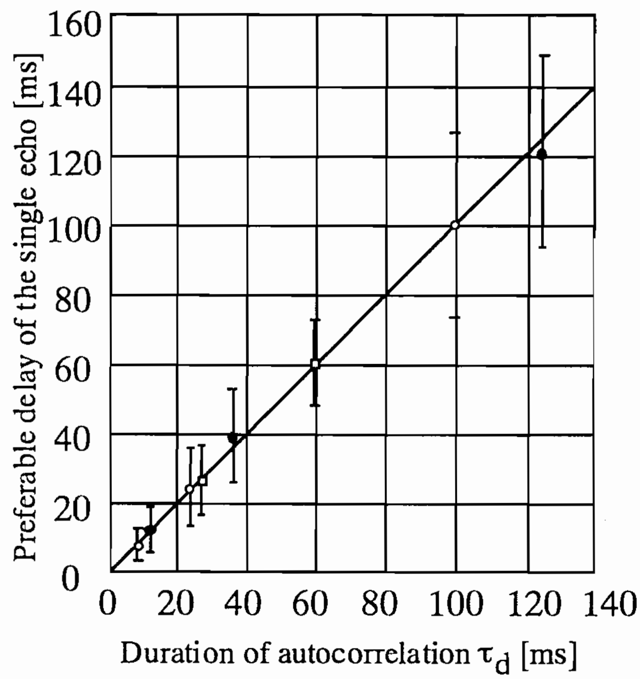


Fig. 2.1 Relationship between the preferable delay of the single echo and the duration of ACF.

Note: Symbols indicate the different echo level of + 6 dB (○), 0 dB (●), and - 6 dB (□), respectively.
Figure was arranged by Ando[15].

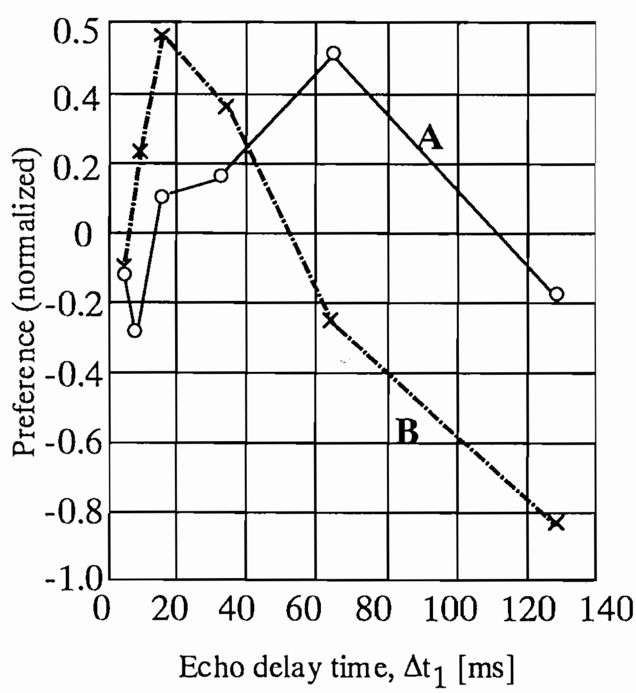


Fig. 2.2 Preference scores of the sound fields as a function of the delay of the single echo at $\xi = 36°$, $A_1 = 0$ dB.

Note: Solid curve indicats the results of Motif A and dash curve indecates the Motif B, respectively.
Figure reference is same as **Fig. 2.1.**

processing (SRP). Concerning SRP for brain waves signal, the estimation of finite length data (N) for the effect of sound field has to discuss a statistical error, and it has two conditions should be considered.

(1) The average values of signal X(t) are constant and independent within arbitrary time domain.

(2) The autocorrelation function (ACF) of signal is also independent in any time span, but only associates with the distance (τ) between two time position (t_1,t_2). And it equals to the expectation of time square average as a definition.

$$\Phi_X(t_1,t_2) = E\,(X(t_1)X(t_2)) = E\,(X(t)X(t-\tau)) = \Phi_X(\tau) \tag{2.1}$$

Where $\Phi_X(\tau)$ is

$$\Phi(\tau) = \lim_{N \to \infty} \frac{1}{N} \sum_{n=1}^{N} x(n)x(n+\tau) \tag{2.2}$$

But for a finite length data (N) will only obtain an estimation of ACF

$$\hat{\Phi}(\tau) = \frac{1}{N} \sum_{n=1}^{N} x_N(n)x_N(n+\tau) \tag{2.3}$$

And the real length of signal for calculation are N-τ, thus

$$\hat{\Phi}(\tau) = \frac{1}{N} \sum_{n=1}^{N-\tau} x_N(n)x_N(n+\tau) \tag{2.4}$$

The expectation of error for estimating are

$$error[\hat{\Phi}(\tau)] = E\,\{\hat{\Phi}(\tau)\} - \Phi(\tau) \tag{2.5}$$

Where

$$E\{\hat{\Phi}(\tau)\} = E\{\frac{1}{N}\sum_{n=1}^{N-\tau} x_N(n)x_N(n+\tau)\}$$
$$= \frac{1}{N}E\{\sum_{n=1}^{N-\tau} x_N(n)x_N(n+\tau)\}$$
$$= \frac{1}{N}\sum_{n=1}^{N-|\tau|} \Phi(\tau) = \frac{N-\tau}{N}\Phi(\tau) \tag{2.6}$$

Therefore, the expectation of error are

$$error[\hat{\Phi}(\tau)] = -\frac{\tau}{N}\Phi(\tau) \tag{2.7}$$

The conclusion are,

(1) When N closes to infinity, error will decrease to 0.

(2) As $\tau << N$, the estimation of ACF are almost equal to the real one.

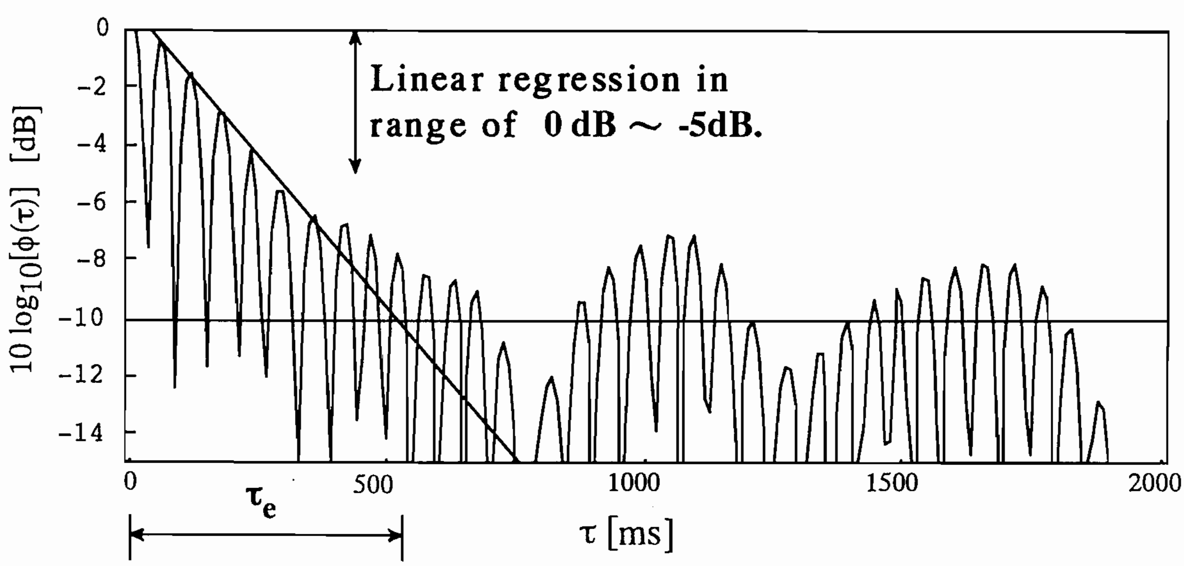


Fig. 2.3 A linear sum in α-waves range of continuous brain waves shows an initial decline of envelope of ACF, and it can be fit to a straight line regression in a range of 0 to -5 dB of the power of the normalized ACF. The effective duration of ACF (τ_e) is defined as it cross to -10 dB at that of delay.

Calculating τ_e, ACF in α-waves range in this study, only initial part of normalized ACF (approximately 0 to -5dB) showed the clearly decay for all data. As indicated as **Fig. 2.3**, an example shows the most normal style in our analysis, the initial part within 500ms were employed for straight line regression well. It satisfied that estimating error was in keeping with under $\tau << N$ (e.g. N = 2.5 s) for ACF calculation. In addition, there were a few cases that showed arising tendency within 0 to -5dB or 0 to 500ms range (see **APPENDIX B**). In such cases the decline part of envelope was only employed for regression. Finally, the value of τ_e defined at the ten-percentile delay (-10 dB) is obtained by fitting the straight-line regression for ($Log(\Phi_X(\tau)) > -5dB$) or ($\tau < 500ms$) of the ACF envelope for all. This procedure is similar to the manner of measuring the initial reverberation time in room acoustics.

2. 3 PSYCHOLOGICAL PRESENT

Regarding the mechanism of momentary memories in psychological studies, Fraisse [16] believed that the "psychological present" which was considered the perception of rhythm that we can perceive needed a time window of about 2.5 s. Inside this time window, sound signals are able to be grasped immediately at present.

As the thurshold of this momentary interval is considered, Wallin [17] gave us two examples: (1) one syllable of adagio of the slowest 9/4 scale do not exceed 5 s, and (2) a sentence of a poem that composed of 13 ~17 temperaments was read, and it can even takes 5s to catch with the momentary impression. But the interval of rhythm structure between two continuous elements should be less than 1.8 s for rhythm constructure. Otherwise, rhythm pattern would be broken into pecies.

To conclude these psychological phenomenon, we considered of a stimulating systematization of paired-comparison. The maximum length between two elements of rhythm structure was considered as a standard stimulating pause between two continuous stimulation. And the perception of a group of tones was used as a stimulating length of 5 s is possible to experience the whole.

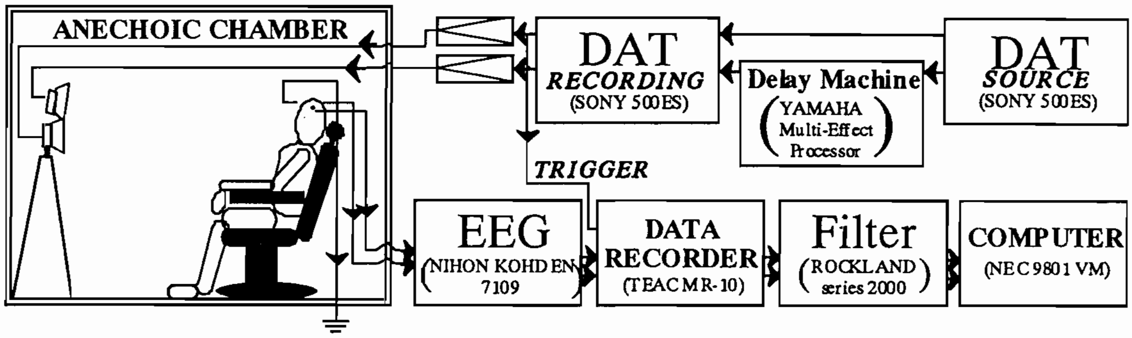


Fig. 2.4 The block diagram of physiological experiment setup in an anechoic chamber. Simulated sound fields that varied the delay time (Δt_1) between direct and the first reflection sound were generated via speakers system (η = 0 and 17°, A_0 - A_1 = 0 dB). Two brain wave channels and the direct sound signal were recorded with brain waves. The brain waves data were analyzed with autocorrelation function technique on computer.

2. 4 EXPERIMENT

2.4.1 Sound Signal and Subjects

According to the psychological present, the sound source was a 5 s peace of music, for 2 oboes, 2 horns, and strings from Arnold's Sinfornietta, Opus 48, from the beginning of the 3rd movement, which was recorded in an anechoic chamber at the BBC by Burd [5]. As shown in **Fig. 2.2**, the most preferred delay time of the single reflection obtained in the paired-comparison tests is found centered on Δt_1 = 35 ms, which corresponds to the minimum effective duration of ACF of the source signal (see Section 1.2.3), the echo disturbance effects are observed at Δt_1 = 245 ms for 13 subject [15]. Thus, these two standards were selected for this investigation.

The participating subjects were eleven male students (A ~ K, 22 ~ 26 years old) with normal hearing ability and all right handed (self admitted). Subjects A, B & C also participated in a preliminary experiment to discuss the optimal integration interval of CBW in ACF analysis. The subjects were seated in anechoic chamber with comfortable thermal environments where they listened to sound fields alternatively with Δt_1 = 35 ms and 245 ms. The amplitude of the

Table 2.1 The conditions of the experiment for CBWs recordings offered the Δt_1 variation with the other constant factors.

Factors	Δt_1	LL	IACC	A value
Setting	35, 245(ms)	78.0$\pm$0.2 (dBA) (slow)	$\approx$ 1.0	1.0

reflection was identical to that of the direct sound. Two loudspeakers were located (1 m) in front of the subject for the direct sound (the elevation was zero) and the reflection (the elevation is 17 degrees), as shown in **Fig. 2.4**. Thus, the IACC of the sound field was kept close to unity. The sound pressure level at the center position of the subject's head was kept constant at 75 dBA. All these setup of the four independent factors are listed in **Table 2.1**. All subjects were prohibited from drinking any alcoholic before a period of three days before the CBWs where recorded and refrained from smoking for one hour before the experiment. They were instructed to concentrate their attention on listening to the music during the presentation.

2.4.2 Analysis of CBWs

The CBWs from the left and right cerebral scalps picked up by silver electrodes at T3 and T4 channels (The International 10 / 20 placement system (**APPENDIX A**)) were amplified and recorded by a data recorder. As illustrated in **Fig. 2.4**, the reference electrodes were positioned on both the left and right earlobes. The ground electrode was placed on the forehead. The CBW signals were analyzed after passing through a digital-bandpass filter with cut-off frequencies (140 dB/octave slops) of 8 ~ 13 Hz: α-wave ranges. The sampling rate was 100 Hz for the ACF analyses. The leading edge of each stimulation trail was recorded simultaneously by a trigger signal.

Ando and Watanabe [18] changed Δt_1 of a sound field to discuss the effects of different presentation methods for SVR recordings. The result revealed that the difference in SVR with the paired-comparison presentation became significantly larger than that with the single presentation regarding a statistical denotation. Furthermore, the cortically electro- activity

Table 2.2. Results of τ_e in α-waves range obtained from the left cerebral hemisphere for global and individual scales by one-way ANOVA. Significant results referred to the effect of Δt_1 in change of integration intervals for ACF analyses.

Subject	summation intervals (N)				
	1.0s	2.0s	2.5s	3.0s	4.0s
A	-	-	L35 > L245***	-	-
B	-	-	-	-	-
C	-	L35 > L245***	L35 > L245***	L35 > L245***	-
Global	-	L35 > L245***	L35 > L245**	L35 > L245***	-

NOTE: L35, for example, denotes the τ_e that referred to Δt_1 = 35ms, *** $p < 0.01$

may correspond to the phenomenon of the "psychological present" was asummed. Therefore, CBW s recording series were repeated three times for each subject, where one series consisted of 10 pairs of sound fields (Δt_1 = 35 and 245 ms), each series about 150 s with 5 s stimuli and 2 s inter stimulus intervals.

Finally, to correspond the subjective preference of the single reflection in a music field, the effective duration of ACF of the α-wave range in CBW, τ_e, was analyzed as described in the Section of **2.2.** The integral interval N (to provide the total summative data in Eq. 2.3) was first discussed from 1 s ~ 4 s intervals to demonstrat the optimal segmantation for CBWs.

2.5 RESULTS

2.5.1 Preliminary test on the Integration Interval in ACF Analyses of the α-waves

First of all, to discuss the integration interval of the α-waves in CBWs in the ACF analyses, which must be 0.5 ~ 5 s long enough to reveal the slowest frequency components, or the minimum time duration needed for subjective judgment, the values of τ_e were obtained by varying the integration from 1 s through 4 s for the beginning of each stimulus trail. As indicated in **Table 2.2**, 2.5 s showed the most significant results of CBW only from the left hemisphere of three subjects A, B and C. Thus, here after all analyses of CBW were performed

Table 2.3. Results of the three-way ANOVA for global (subject A ~ K) values of τ_e in α–waves range with the factors of subjects, the effect of Δt_1(35, 245ms) and hemispheric difference (LR).

Source	F-Ratio	p-value
Subject	93.12	<0.001***
LR	0.97	0.324
Δt_1	5.79	0.016**
Subject*LR	8.87	<0.001***
Subject*Δt_1	0.42	0.939
LR*Δt_1	9.61	0.002***
Subject*LR*Δt_1	0.40	0.945
Subject*LR*Δt_1	0.40	0.945

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

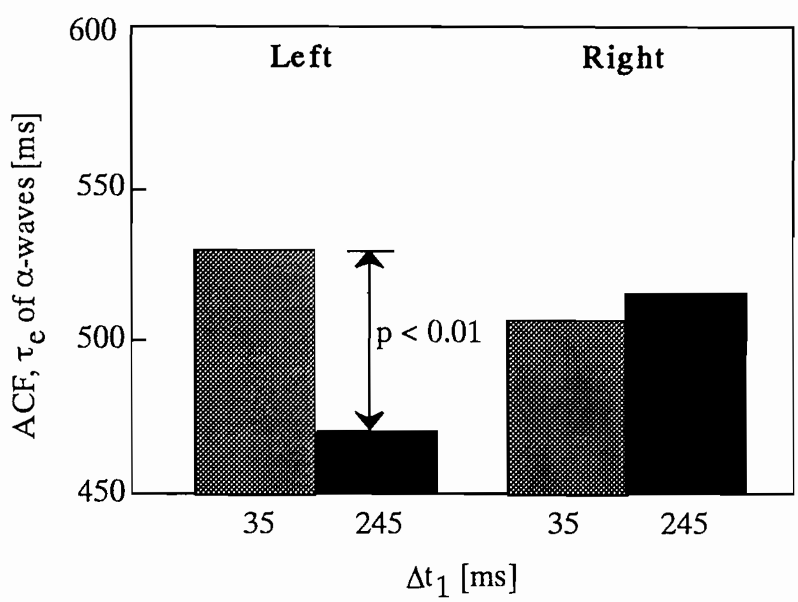


Fig. 2.5 Average value of τ_e of ACF (2T = 2.5 s) in the α-wave range responding to Δt_1 = 35ms and Δt_1 = 245m for three series of all subjects (A ~ K).

at this particular integration interval. It is worth noticing that this interval is nearly the same to obtain the minimum effective duration of the running ACF of source signals corresponding to the subjective preference judgments [2].

2.5.2 Values of τ_e of α-waves

Effects of the delay time of the reflection (Δt_1) and the hemispheres (LR) on the value of τ_e of ACF for the α-waves in CBW were examined with all eleven subjects using the three-way (2 x 2 x 11) analysis of variation (ANOVA), as shown in **Table 2.3**. Although, individual differences in the value of τ_e are significant, there are no interference effects between factors, the subject and Δt_1, so that effects of Δt_1 on the value of τ_e are quite clearly ($p < 0.025$) independent on the subjects. However, there are significant interference effects between the subjects and LR ($p < 0.01$). Thus, accumulating values of τ_e in respect to the subjects for each hemisphere, and the effects of Δt_1 on the value of τ_e were examined using the one-way

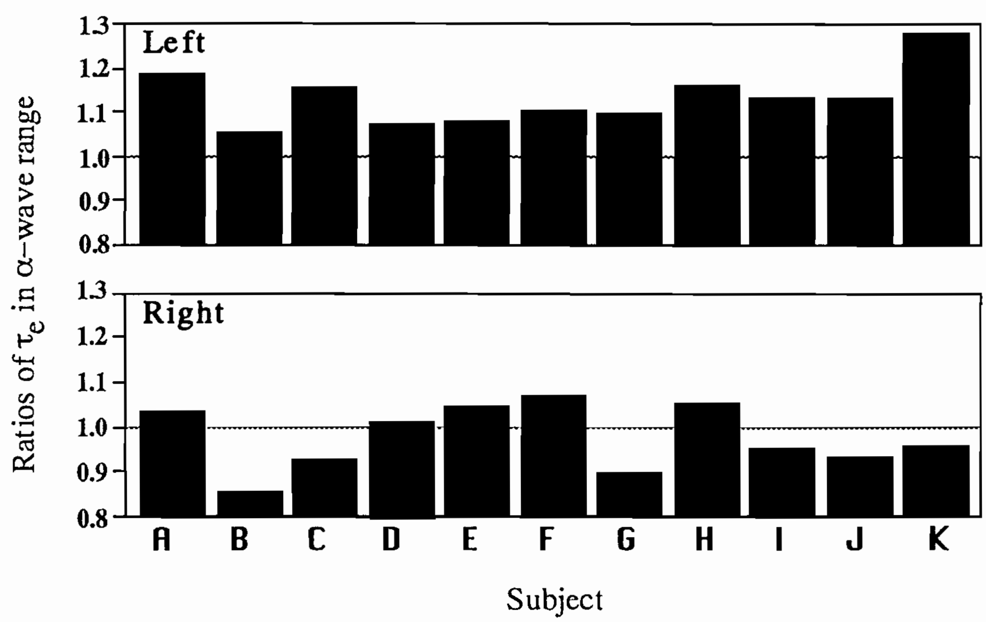


Fig. 2.6 Ratios of τ_e value in α-wave range obtained by the responses at Δt_1 = 35 ms normalized by Δt_1 = 245 ms.

ANOVA. As shown in **Fig. 2.5**, it was found that the effects of Δt_1 is significant only in the left hemisphere ($p < 0.01$).

Furthermore, in the left hemisphere, averaged values of τ_e obtained for each subject in the three series are consistently longer at $\Delta t_1 = 35$ ms than those at $\Delta t_1 = 245$ ms. Ratios of averaged values of τ_e at $\Delta t_1 = 35$ ms to those at $\Delta t_1 = 245$ ms, shown in **Fig. 2.6** are clearly greater than unity in the left hemisphere, but ratios fluctuate around unity in the right hemisphere depending on the subject ($p < 0.01$). The average values of every subject in each EEG channel were listed in **Table A-2**.

2. 6 DISCUSSION AND CONCLUSIONS

2.6.1 Discussion

The above mentioned conclusion may reveal left hemisphere dominance when Δt_1 is varied, and confirms a previous study [13]. It is reported that the left hemisphere is dominantly associated with speech and time sequential identification, and that the right hemisphere is concerned with nonverbal and spatial identifications [9]. When the listening level of a continuous speech signal was varied in a pair, however, the right hemisphere was activated significantly [14]. Thus, hemispheric dominance is considered to be a relative phenomenon depending on whether temporal or spatial factors are changed in the stimulus pair [19][14].

The effective duration of ACF for α-waves in CBW is prolonged with a certain degree of coherency at the preferred condition. This may be interpreted in such a way that a similar repetitive feature in the α-waves for 2.5 s intervals is evoked due to comfortable relaxation which may be repeated in the mind. The α-wave is known as the longest period of continuous brain wave in the human awaking stage. In a drowsy stages, longer periods than those of α-waves appear in the CBW. This is, at least partially, related to the fact that the N2-latency in SVR is prolonged in preferred condition [9][14].

2.6.2 Conclusions

Averaged values of effective duration of ACF for the α-waves in CBWs for each subject obtained in the three series are consistently longer at the preferred condition of Δt_1 = 35 ms than those at the echo disturbance condition of Δt_1 = 245 ms. This is observed only in the left hemisphere, however ($p < 0.01$).

2. 7 SUMMARY

(1) Optimized stimulation system (paired-comparison system) and segmentation correlates well to the subjective preference in 2.5 s by considering the "psychological present".

(2) The effective duration of ACF (τ_e) of CBW in α-waves range efficiently corresponds to the subjective preference, and prolongs as the scores of preference higher.

(3) The EEG channels T3 is a forcible measuring for detecting the time charactertistic variation.

CHAPTER III

AUTOCORRELATION FUNCTION OF α-WAVES RELATIVE TO THE REVERBERATION TIME OF MUSIC SOUND FIELD

3. 1 INTRODUCTION

3.1.1 An advancement for relationship between CBWs and subjective preference

We know the reverberation time (T_{sub}) is frequently measured as a standard of the psychoacoustic design. As the knowledge in the previous chapter, the relatioship between α-waves range of CBWs and the scale value (SV) of the subjective preference is being tried to advance to another temporal factor, T_{sub}. To enhence the correlation, the preference scores of individual subject (a ~ j) were tested here, the result of SV for 10 subjects was centered on 1.2 s. Accordingly, we represented 1.2 s of the T_{sub} signal for comparison with the two less preferred, 0.2 s and 6.4 s in running pairs for recording CBW, respectively. Then, the effective duration (τ_e) of the autocorrelation function in α-waves range was analyzed. The values of τ_e form the left hemisphere of the subjects all over show a significant agreement with the SV of the subjective preference on the (0.2 and 1.2 s) pair with few individual differences. It is remarkable that the individual preferences for 6.4 s in comparison to that for 1.2 s correlate well with the individual ratios of the τ_e of 1.2 s to the τ_e of 6.4 s also in the left hemisphere ($r = 0.70$, $p < 0.05$).

3.1.2 The conventional studies on AEP in relation to subjective preference

Investigating the relationship between the brain activities and the subjective preference as to change in the LL, Δt_1 and IACC of the sound field, Ando [8] found cerebral hemispheric dominance and the relationship between subjective preference and the N2-latency of SVR. However, such an evoked potential method cannot be applied for characterizing longer stimulus signals than 0.9 s. For this purpose, the method for analyzing the ACF of the α-waves for the CBW was employed in previous chapter on changing Δt_1.

In present chapter, the CBW are analyzed to examine whether a strong coherence exists between τ_e , ACF of them and the subjective preference for music sound field when T_{sub} is changed. In addition, since T_{sub} belongs to a temporal factor as introducted in chapter I, we assume a significant tendency in the left hemisphere also.

3. 2 EXPERIMENT

3.2.1 Preferred reverberation time

Ando, Okano and Takezoe [2] reported that the minimum value of effective duration of a running autocorrelation function for a sound source can be used to evaluate the subjective preference for a sound field. The results of the subjective preference test show that the $(\tau_e)_{min}$ of the source signal can indicate a relation to the preferred T_{sub}, calculated by Eq. 1.13. Here, the same music source signal as changing Δt_1 composed by Arnold [5], is denovo measured

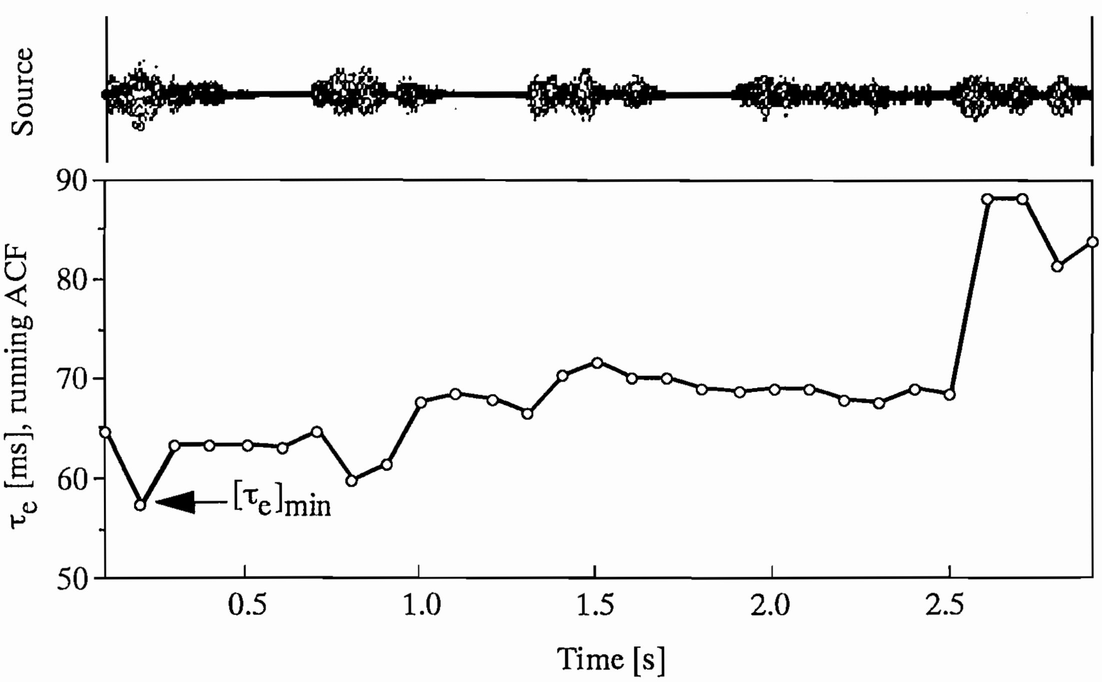


Fig. 3.1 Effective duration of the running ACF with a 100 ms running step as a function of time of music Motif B (summation interval N = 2 s in Eq. 2.3).

Table 3.1 Reverberation time varied and the three other factors fixed constantly for subjective judgement tests (a). Stimulus signals for recording brain waves (b), the T_{sub} changing were selected from the results of the preference judgement.

(a) Subjective preference test

Factors	T_{sub}[s]	LL [dB]	Δt_1 [ms]	IACC
Setting	0.2, 0.4, 0.8, 1.2, 1.6, 2.4, 3.2	75.0 ± 0.2	40	≈ 1.0

(b) Brain waves recording

Setting	0.2, 1.2, 6.4	75.0 ± 0.2	40	≈ 1.0

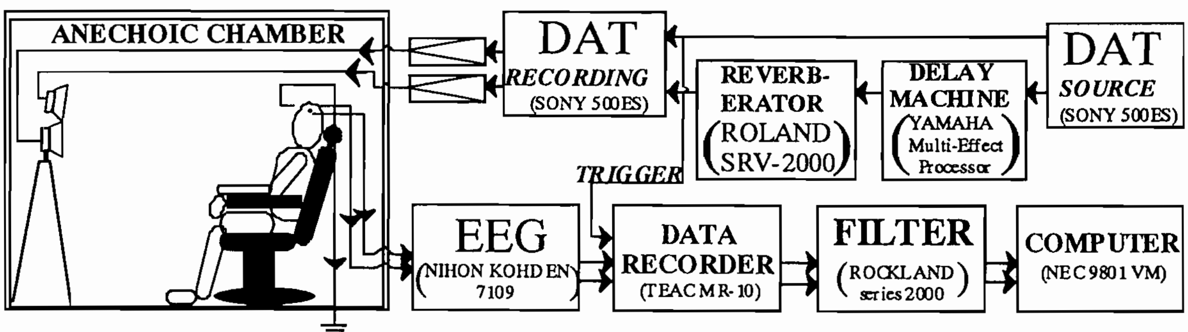


Fig. 3.2 Block diagram of the subjective preference test and the brain waves analysis.

as the value of $(\tau_e)_{min}$ = 57 ms, indecated as in **Fig. 3.1**. Thus, for this piece of music, calculated $[T_{sub}]_p$ by Eq. 1.13 is about 1.3 s. The other physical factors of the sound field were fixed at constants as illustrated in **Table 3.1**. Two loudspeakers were used to produce the direct sound and the subsequent reverberation and the reflection (η = 0° and 17°, illustrated in **Fig. 3.2**). These two amplitudes were fixed at A_0 = 1 (the direct sound) and A_r = 2 (the total amplitude of reverberation), and the A values (Eq. 1.12) equals to 2. Thus, we can measured it by a logarithmic normalized ACF at τ = 0 as below,

$$20 \log A = 10 \log A_r^2 - 10 \log A_0^2 = 10 = 10 \log \phi_r(0) - 10 \log \phi_0(0) \approx 6 \text{ dB}.$$

To keep the IACC nearly unity, two loudspeakers were situated in front of the subject at a distance of 1m apart. All mesurements have bypassed an A-weighting filter.

The delay time of the first reflection (Δt_1) was kept at a constant value (40 ms) in the preferred condition, which is calculated according to the expression of Eq. 1.11.

3.2.2 Preference tests and subjects

The reverberation time was changed at 7 levels from 0.2 to 3.2 s (**Table 3.1**). The stimuli were each approximately 5.0 s duration. Following the paired-comparison method, we presented 21 pairs of stimuli at a session (**Fig. 3.3**), and 15 sessions were conducted with every subject. The subjects (a ~ j) are different from previous study, they ranged in age from 25 to 33 years, for an average age of 29. They also had normal hearing ability and all right-handed (self-reported). The presentation intervals between stimuli within a pair were 2 s, with a 4 s interval between pairs to allow for subject's response. Subjects reported which

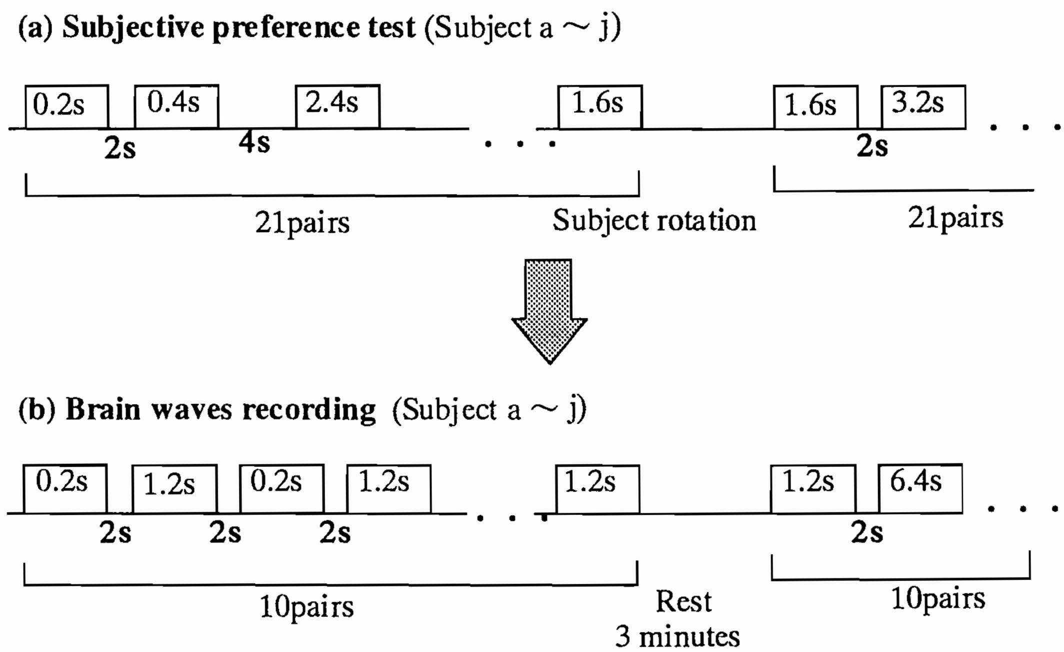


Fig. 3.3 The procedures of subjective preference tests and brain waves recording with respective to the paired-comparison presentation method to enhence both (a) psychological and (b) physiological effects.

sound field in the pair they preferred to hear, and pushed a button to record their responses.

The scale value (SV) of the subjective preference of each subject was calculated according to Case V of Thurstone's theory [4]. As shown in **Fig. 3.4**, the most preferred T_{sub} was about 1.2 s averaged among 10 subjects. It is worth noticing that the most preferred T_{sub} of motif B is 1.3 s which is calculated according to Eq. 1.13 with $(\tau_e)_{min}$ = 57 ms [2]. There is a certain degree of agreement for all subjects on the subjective judgement, especially, for scale values from 0.2 to 1.2 s. But, large individual differences for the differences of the scale values from 1.2 to 3.2 or 6.4 s are obvious. Therefore, there is no good coincidence between the observed values and the fitted values, which was examined by Mosteller [20] method.

3.2.3 Recordings of the CBW

The stimulus signals were presented by a running repetition of pairs. The same subjects (a ~ j) as for the preference test participated. To find significant effects on CBW, we paired the most preferred reverberation time (1.2 s) and the worse (0.2 s). To enhance the differences

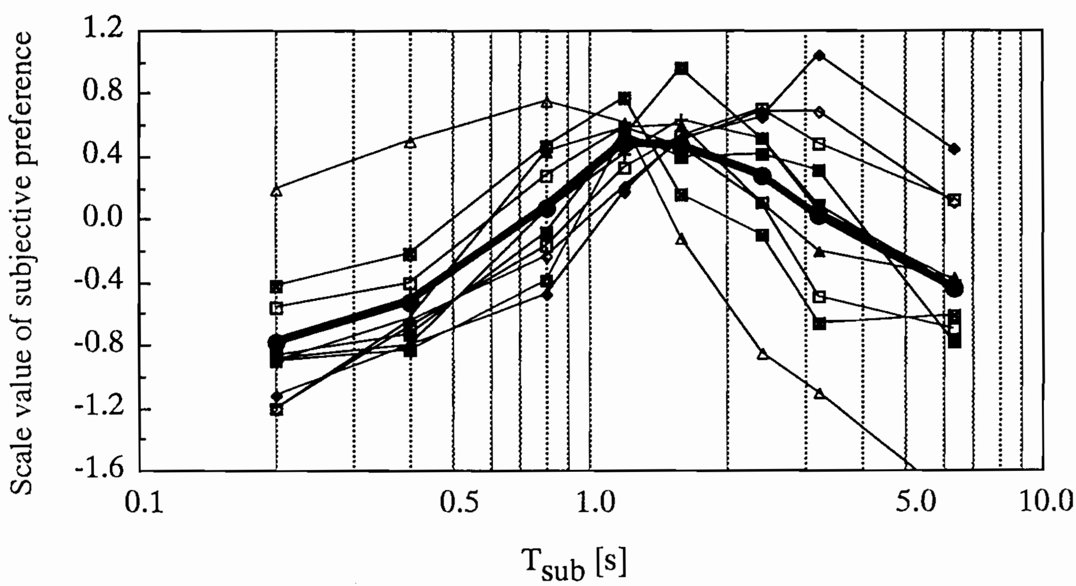


Fig. 3.4 The scale values of the subjective preference for reverberation time (T_{sub}) of 10 subjects (a ~ j). A certain agreement from 0.2 to 1.2 s is found. The scale values at T_{sub} = 6.4 s are calculated by extrapolation with Eq. 3.1.
Note: Symbol illustration:
Subject:
a —□— b —◆— c —■— d —◇— e —■— f —□— g —▲— h —△— i —■— j —+— Average —●—

of preference in the range 1.2 to 3.2 s (**Fig. 3.4**), we further selected a longer reverberation time (6.4 s) to be paired with 1.2 s (1.2 and 6.4 s). These two kinds of pairs were presented successively every ten times in each series for simultaneous recordings of brain waves. The intervals between pairs were all set at 2 s. The subjects listened to three series (thirty pairs) with a 3-minutes interval between series as refreshment.

The sound pressure level at the center position of the subject's head was kept constant at 75 dBA (**Table 3.1**). All subjects were prohibited from drinking any alcoholic in the period of experiment, before the CBW were recorded, and refrained from smoking for one hour before brain waves were recorded. They were instructed to concentrate their attention on listening to the music during the presentation. The CBW were recorded simultaneously from T3 and T4 of two unipolar electrodes by means of the international 10/20 scheme (**APPENDIX A**). The reference electrodes were attached to each earlobe right and left, and the ground electrode to the center front head (**Fig. 3.2**). The CBW were amplified through a polygraph and recorded by a data recorder with stimulating signals as a trigger. The CBW signals were analyzed after passing through a bandpass filter (cut-off slope: 140 dB/oct.), 8 ~ 13 Hz (α-wave range), with sampling at a rate of 100 Hz.

3.2.4 Analyses of CBW

To derive a degree of similar repetitive features in the α-wave range of CBW, the effective duration of the ACF, τ_e, was analyzed as previous study. The regression lines that satisfied 0 dB > $\log[\phi(\tau)]$ > -5 dB or 0 ms > τ > 500 ms ranges (see also **APPENDIX B**), and crossed to the line of -10 dB on the τ axis of the ten-percentile delay, were taken as τ_e of the α-wave. This procedure is effective as described in the previous chaper on changing the Δt_1 of music sound fields.

3. 3 RESULTS

3.3.1 Values of τ_e of α-waves

Concerning the values of τ_e in the α-waves range, three-way analysis of variance (ANOVA) was performed by examining a 10 x 2 x 2 level classification matrix for the factors

Table 3.2 Results of the three-way ANOVA for the values of τ_e for the α-waves responding to the factors subjects, effects of T_{sub} and hemispheric difference (LR, left/right) for pair of (a) (0.2 and 1.2 s) and (b) (1.2 and 6.4 s), respectively.

(a) Pair of (0.2 and 1.2 s)

Source	F-Ratio	p-value
Subject	40.937	< 0.001***
LR	2.087	0.149
T_{sub}	6.209	0.013**
Subject*LR	2.804	0.003***
Subject*T_{sub}	1.232	0.271
LR*T_{sub}	13.958	< 0.001***
Subject*LR*T_{sub}	1.381	0.192

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

(b) Pair of (1.2 and 6.4 s)

Source	F-Ratio	p-value
Subject	42.005	< 0.001***
LR	1.989	0.159
T_{sub}	0.018	0.894
Subject*LR	2.047	0.032**
Subject*T_{sub}	2.748	0.004***
LR*T_{sub}	0.203	0.652
Subject*LR*T_{sub}	0.657	0.748

Table 3.3 Results of one-way ANOVA for values of τ_e pertaining to the effects of T_{sub}, which are divided between the left and right cerebral hemispheres for pair of (a) (0.2 and 1.2 s) and (b) (1.2 and 6.4 s), respectively. The significant difference is obtained between 0.2 s and 1.2 s in the left cerebral hemisphere only.

(a) Pair of (0.2 and 1.2 s)

	F-Ratio	p-value
Left	15.310	< 0.001***
Right	0.635	0.426

NOTE: *** p < 0.01

(b) Pair of (1.2 and 6.4 s)

	F-Ratio	p-value
Left	0.002	0.963
Right	0.159	0.690

of subjects (a ~ j), hemispheric difference (LR), and T_{sub}. The results of ANOVA for the τ_e of the α-waves for each pair of T_{sub} are indicated in **Table 3.2**. Though significant differences between subjects are found ($p < 0.01$), the effects of T_{sub} is found only on the (0.2 and 1.2 s) pair ($p < 0.025$). And, no interference effects are found between the factors subjects and T_{sub} on the (0.2 and 1.2 s) pair, so that the factor of the subjects all over is additive on the statistical identification for the effects of T_{sub}. Since there is the interference between LR and T_{sub}, we further examined the accumulating values of τ_e in respect to the subjects, and the effects of T_{sub} on the value of τ_e for each hemisphere using one-way ANOVA (**Table. 3.3**). Significant differences ($p < 0.01$) are obtained for the (0.2 and 1.2 s) pair on the left hemispheres only.

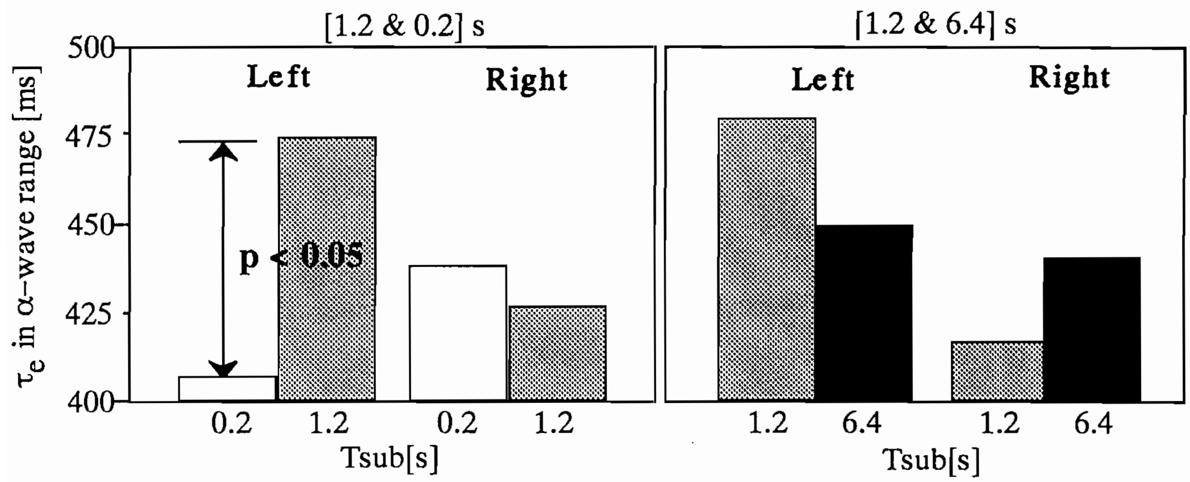


Fig. 3.5 Averaged values of τ_e in the α-wave range for 10 subjects (a ~ j) responding to the both reverberation pairs.

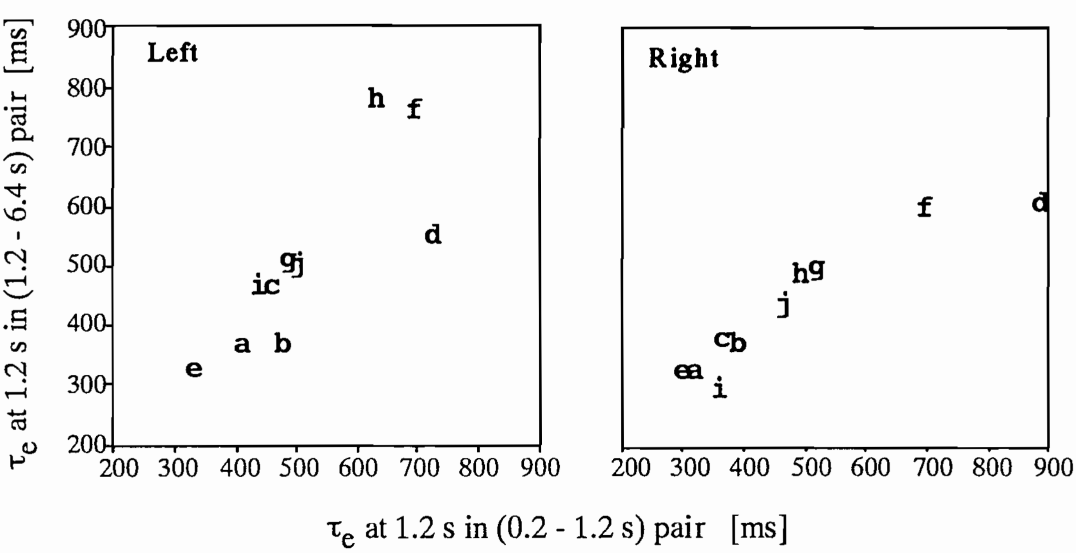


Fig. 3.6 Relationship between the values of τ_e for the α-waves at $T_{sub} = 1.2$ s obtained in (0.2 and 1.2 s) pair and (1.2 and 6.4 s) pair in the both hemispheres for each subject (a ~ j). The correlation coefficient is 0.81 ($p < 0.01$) in the left hemispheres and 0.93 ($p < 0.01$) in the right.

As shown in **Fig. 3.5**, the averaged value of τ_e at the most preferred T_{sub} = 1.2 s for the left hemisphere of each pair are always longer than those other at T_{sub} = 0.2 s or 6.4 s.

The individual results analyzed by two-way ANOVA by examining 2 x 2 level classification and the averaging tendency for individual were indicated in **APPENDIX C** as reference.

With a view to the paired presentation method for brain waves recording, τ_e values of the α-waves at T_{sub} = 1.2 s are consistently obtained between two pairs in the both hemispheres for individual subjects (**Fig. 3.6**). The average τ_e values of the α-waves at T_{sub} = 1.2 s for each subject show a good correspondence between (0.2 and 1.2 s) pair and (1.2 and 6.4 s) pair (correlation coefficient = 0.81 ($p < 0.01$) in the left hemispheres, and 0.93 ($p < 0.01$) in the right).

3.3.2 Individual differences

To discuss individual differences, the ratios of the averaged τ_e values at T_{sub} = 1.2 s to those at T_{sub} = 0.2 s for each subject are shown in **Fig. 3.7** (a). It is obvious for each individual that the ratios are consistently greater than unity in the left hemisphere without any exception ($p < 0.01$), but fluctuate around unity in the right hemisphere. On the other hand, great significant differences in individual preference are found within the range of $T_{sub} > 1.2$ s (**Fig. 3.7** (b)).

These individual results of τ_e values correspond well to the scale values for individual subjective preference. In facts, the ratios of the τ_e values of the α-waves at (1.2 and 6.4 s) pair ([τ_e (1.2 s) / τ_e (6.4 s)]) correspond well to the differences in the scale values ([SV (1.2 s) - SV (6.4 s)]) for every individual as shown in **Fig. 3.8**, where scale values for T_{sub} = 6.4 s are extrapolated as shown in **Fig. 3.9** using the behavior function (Eq. 1.5) proposed by Ando [1] for the subjective judgement as below.

$$SV \approx -a|X|^{3/2}$$

where
$$X = \log\left(\frac{T_{sub}}{[T_{sub}]_p}\right). \qquad (3.1)$$

and a denotes the single weighting coefficient to account for the individual differences for the

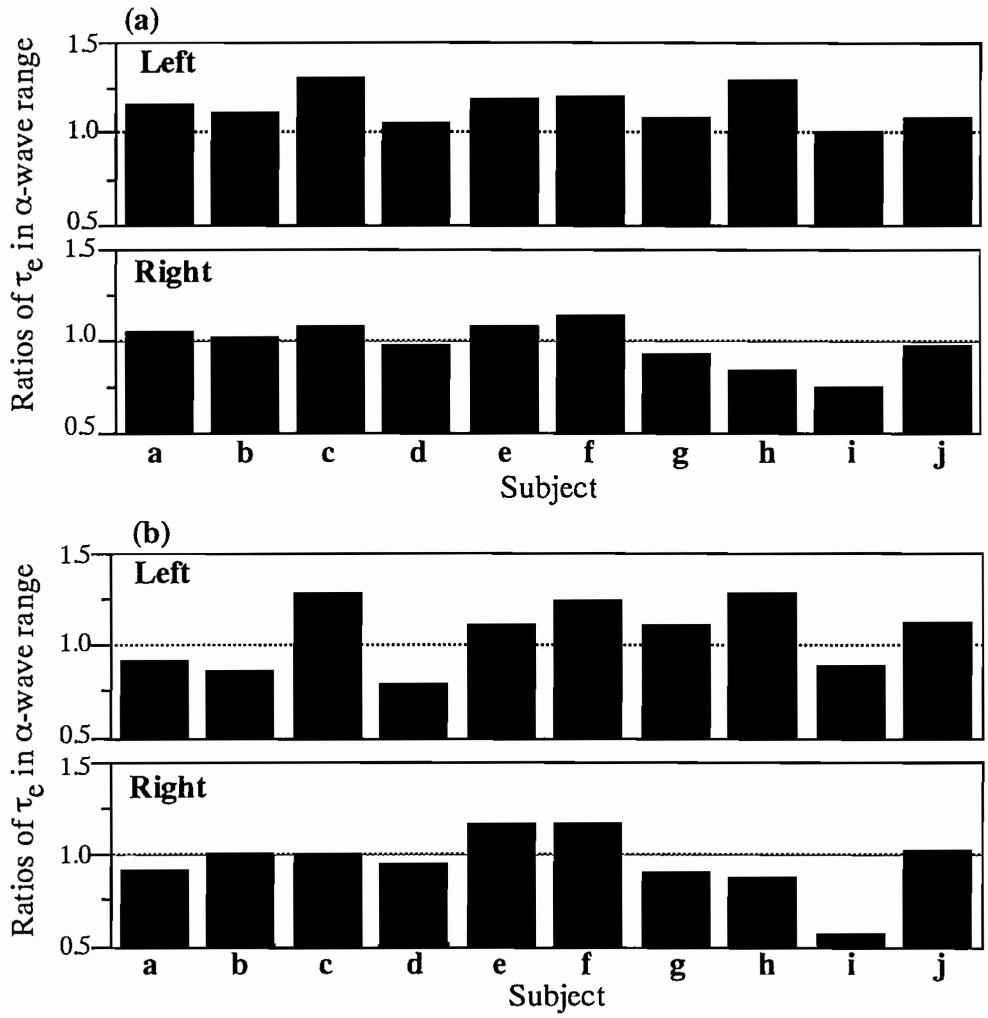
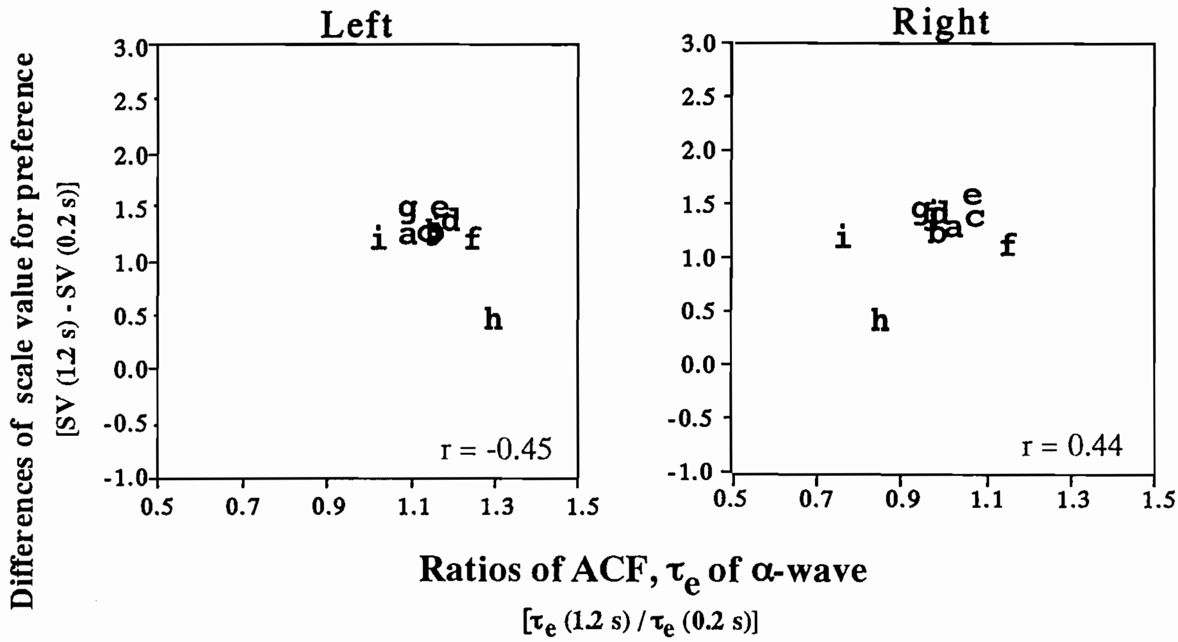


Fig. 3.7 Ratios of values in the α-wave range which responded to the changes of T_{sub} for 10 subjects (a ~ j). They show consistent rates (larger than unity) in the left cerebral hemisphere for (0.2 and 1.2 s) pair only ($p < 0.01$, $F(1, 18) = 10.6$).
(a) [τ_e value at 1.2 s] / [τ_e value at 0.2 s]; (b) [τ_e value at 1.2 s] / [τ_e value at 6.4 s].

curve of the 3/2 power of the both positive and negative value of X. The values of $[T_{sub}]_p$ is the preferred T_{sub} for each subject was substituded.

(a) [1.2 & 0.2] s



(b) [1.2 & 6.4] s

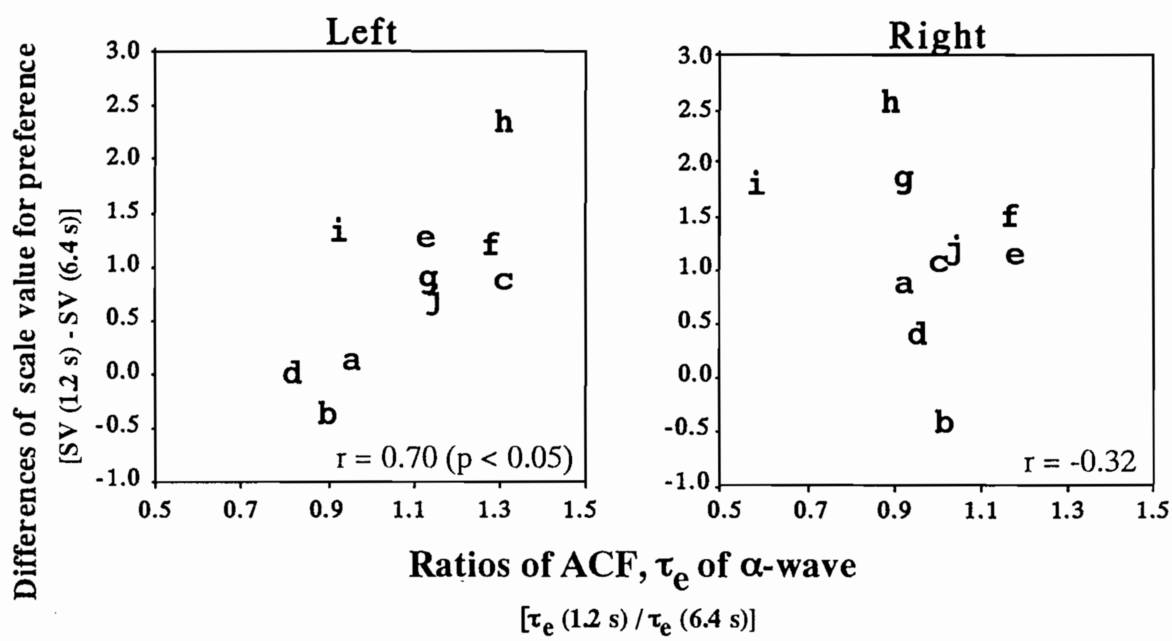


Fig. 3.8 Correlation coefficient (r) between differences of the scale values of preference [SV (1.2 s) - SV (6.4 s)] and ratios of [τ_e (1.2 s) / τ_e (6.4 s)] of α-waves for each subject (a ~ j) are higher than that of (a) [1.2 & 0.2] s. Since the individual subjective differences well coincidence with the variation of τ_e, ACF in α-waves range.

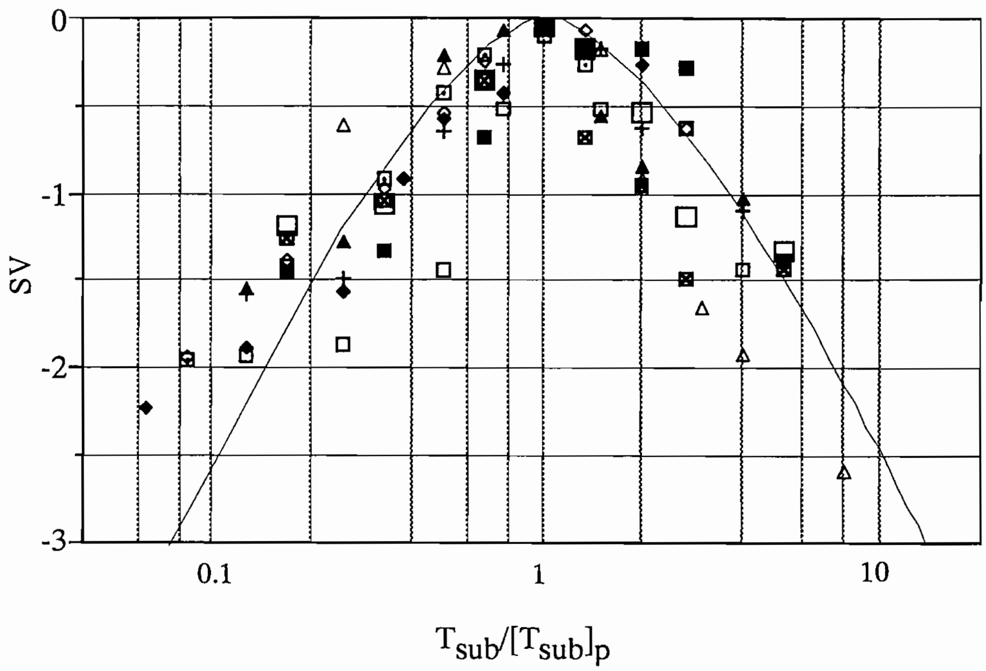


Fig. 3.9 The scale values (SV) for 10 subjects were normalized by the individual preferred level ($[T_{sub}]_p$) functions, and a prediction of the SV at T_{sub} = 6.4 s was calculated by the behavior function of subjective preference (Eq. 3.1). The solid curve shows an averaging tendency of the single weighting coefficient a = 1.875.

Note: Symbol illustration:

Subject: a ◘ b ◆ c ◻ d ◇ e ■ f □ g ▲ h △ i ■ j +

3.4 CONCLUSIONS

At the preferred condition T_{sub} = 1.2 s, α-waves having a significantly longer τ_e are found as referred to that at T_{sub} = 0.2 s, only in the left hemisphere for each subject without any exception ($p < 0.025$) (**Fig. 3.7** (a)). This tendency at the preferred condition is similar to the results of our previous study in changing Δt_1. Individual differences of subjective preference between T_{sub} = 1.2 s and 6.4 s are significantly related to the ratios of the τ_e values of the α-waves obtained only in the left hemisphere for each subject (**Fig. 3. 8**, correlation coefficient = 0.70 ($p < 0.05$)).

3.5 SUMMARY

(1) Hemispheric difference is obtained by the reason that effects of T_{sub} only found in the left hemisphere. This phenomenon is consistently found in the previous study changing Δt_1.

(2) The effective duration of ACF in the α-wave range may function well to the scale values of subjective preference.

CHAPTER IV

AUTOCORRELATION FUNCTION OF α-WAVES AND SUBJECTIVE PREFERENCE RESPONDING TO THE NOISE-BURST TEMPO

4. 1 INTRODUCTION

4.1.1 Preface

A simple time cognition, "period" is wished to improve the relationship between CBWs and subjective preference in present chapter. Whether or not the subjectively preferred tempo responding to periodic noise- bursts reflect the temporal information in continuous brain waves (CBW). The experimental condition was designed to examine: (1) the hemispheric specialization on as temporal aspect, (2) a relationship between subjective preference and effective duration (τ_e) of the autocorrelation function (ACF) in α-waves range.

According to the results of the paired-comparison tests, the most preferred period was found around 550 ms. From the analysis of the τ_e values in α-waves range, the hemispheric difference is identified by periodic effects ($p < 0.001$) which were obtained only in the left hemispheres at periods of 550 ms, referred to 300 ms and 1,000 ms. The global results also show the significantly periodic effects ($p < 0.001$) are thoroughly found in both periodic pairs.

4.1.2 Review

I) Time for environments

This investigation is to obtain a basic knowledge of the temporal aspect of human and the environments. In an environmental design proposed by Ando, Johnson and Bosworth[21], interesting in time perception, it has focused upon the spatial and temporal characteristics of life in physical environments. They also revealed a possibility of developing a correlation between brain activities and the subjective preference for environmental planning. Meanwhile, Ando, Okano, and Takezoe[2] have also proposed a subjective preference of the delay time between the direct sound and the first reflection in a sound field. They have developed a method to evaluate the preferred sound field by calculating the running autocorrelation function (ACF) of music source-signals. This theory has already been applied in the design of several concert halls[19][22][23][24].

II) The standpoint of classical physics for periods

Further, in the standpoints of time consciousness, the time interval between two stimuli and the stimulus length (duration) are indeed examined. Drake and Botte[25] proposed that two distinct methods should be considered as to detect how small changes in time interval are we able to notice. One method is used to judge the duration of single interval and the other one is for judging the stimulus sequences (interval numbers are greater than one). The second method that has been considered involves two points of changing duration and changing interval for frequency, however the functioning requires longer and more elaborate sequences. In the early procedures (regular sequences), Drake and Botte changed the interonset intervals ranging from 100 to 1,500 ms with a constant duration (50 ms, 440 Hz tone), the number of intervals were also changed to 1, 2, 4 and 6. The result was, the most sensitive interval were detected between 300 to 800 ms with no interaction between the factor of intervals and the number of them. This interval range involve a sensitive zone (intervals from 500 to 700 ms) with its maximum sensitivity around 600 ms for detection reported by Fraisse[16][26]. He summarized that the "preferred tempo" of human beings is detected at a similar rate to the naturally "voluntary tempo", which is in harmony with heart beat, walking rhythm, clapping hands, and so forth. The constancy of this phenomena was identified by Mishima[27][28], he studied using auditory (metronome), visual (flickering lamp) stimuli and other behaviors (tapping, walking, finger-tips) related to that named "mental tempo", to ask for a measurement of preferred period of each behavior for each subject. The results showed that mental tempo is constant among behaviors under normal and distractive condition, or in a reference of sexual difference. Recently , to extract the human's preferred tempo and rhythm pattern by means of computer was regarded. Kukimoto and Takeda[29] believed more flexible communication between computer and human's movement will be obtained.

4.1.3 The purpose of present study

We have investigated the sound stimulation responding the temporal information in the brain, and evaluated them by calculating the effective duration (τ_e) of ACF in α-waves range of the continuous brain waves (CBW). The values of τ_e in the left hemispheres significantly prolong with subjective preference scores increasing for changing of the delay time of the single reflection (Δt_1) and the subsequence reverberation time (T_{sub}) in a music sound field in the chapter II and III.

In this study, the subjective tempo is at first identified by the paired-comparison method. A reasonable evaluation for the temporal consciousness is also obtained. Thereafter, this simplified image of the changing subjective tempo is then applied in order to examine the variation of the ACF, τ_e, of CBW.

4. 2 EXPERIMENT

4.2.1 Stimulus sound and subjects

The preferred period is assumed to be a similar interval for subjects who can adapt it to count the numbers of components in sequence without strain. Depending on the specific purpose of both the subjective judgements and the brain waves' analyses, we used the regular sequences with a constantly sequential length in this study. The white noise was provided for noise bursts in 10 ms. All of them had every 3 ms arise interval and reduce decay with a 4 ms ustained-amplitude (65 dB(A)) duration as shown in **Fig. 4. 1.** The wideband noise was used since it is highly discriminable over a large range of duration detection[30]. Periods that begin on the onset to the next noise bursts were between 300 ms and 1,000 ms (300, 400, 550, 700, 850 and 1,000 ms). Sequential chains were all approximately 6.15 s, thus, the numbers of components in each sequence were 20, 14, 10, 8, 7 and 6. All of the stimuli were presented by a loudspeaker (100 Hz ~ 10 kHz; ± 2 dB) placed in the front of the subjects in a distance of 1 m apart.

Ten healthy subjects (A ~ J) all had normal hearing ability and were all right-handed (self-reported). Their ages ranged from 22 to 33 years old (M = 24.1, SD = 3.3).

4.2.2 Subjective preference tests

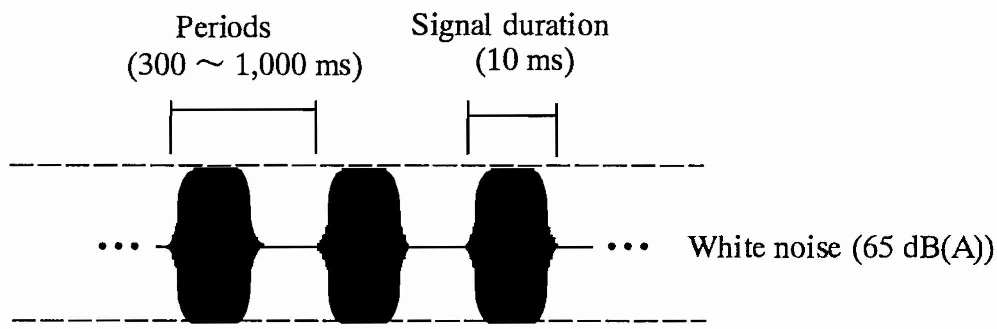


Fig. 4. 1 Production of tempo made by regular sequence of noise-bursts (stimulus duration =10 ms).

In the present study, the intervals between stimulus sequences of the paired-comparison test were all 2.0 s for the purpose of distinguishing two tempi. Next, 15 stimulus pairs were randomly combined in sessions, among them 8 sessions were conducted each with ten subjects. The intervals among two comparison pairs were 4.0 s in order to allow for subject's responses. Subjects reported which tempo in a pair they preferred to follow, and pushed a button to record their responses.

The scale value (SV) of the subjective judgement of each subject was calculated according to Case V of Thurstone's theory[4] (see Section of 1.2.2), and the model was reconfirmed by the goodness of fit[20]. As shown in **Fig. 4. 2**, the most preferred period was centered at 550 ms among ten subjects. There is a certain degree of agreement among all subjects in the subjective judgement, more especially, the periods range from 300 to 550 ms. However, substantial individual differences for the scale values from 550 to 1,000 ms are obvious. Thus, the preferred model's suitability of the average preference scores was examined. The result of the goodness of fit indicated the model had a good match between fitted values and the observed values ($\chi^2 = 12.9 < \chi^2_{10}(0.05) = 18.3$).

In the calculating the SV of subjcetive preference, the agreement of individual response also examined. The data rejection of agreement test were indecated in **APPENDIX D**.

4.2.3 Recordings and Analyses of the CBW

To find significant effects of tempo on CBW, the most preferred period, 550 ms, and

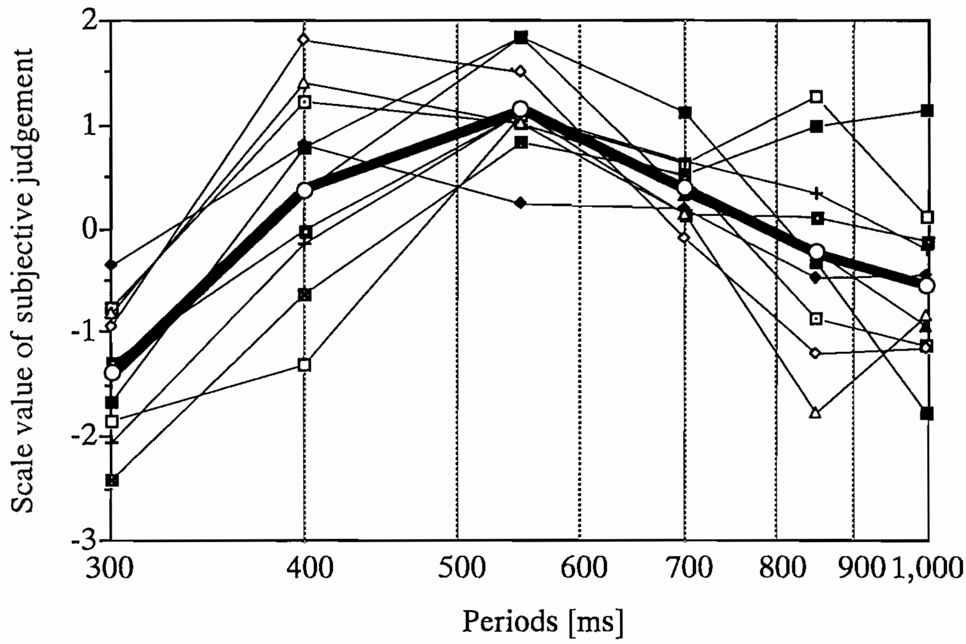


Fig. 4. 2 Results of the scale values of the selective preference obtained by the paired-comporison judgements with ten subjects (A ~ J).
Note:Symbol illustration:
Subject: A B C D E F G H I J Average

the least preferred period, 300 ms, were selected ([550 & 300] ms pair) during the study. In order to refer the individual differences of preference (**Fig. 4. 2**), [550 & 1,000] ms pair was also selected. These two kinds of pairs were successively presented every thirty times with the 2.0 s repetitive interval.

One theory of the hemispheric specialization has verified the temporal characteristics are dominated by the left hemisphere. This was confirmed lately by analyzing the ACF of CBW with respect to the variation of Δt_1 and T_{sub} in a music sound field in previous chapters. Therefore, the CBW were recorded simultaneously from T3 and T4 of two unipolar electrodes by means of the international 10 / 20 placement system (see **APPENDIX A**). The CBW signals were analyzed after passing through a digital filter (cut-off slope: 140 dB/oct.), 8 ~ 13 Hz (α-wave range), with sampling at a rate of 100 Hz. During the study, all subjects were prohibited from drinking any alcoholic beverage. They were refrained from smoking for one hour before their brain waves were recorded. They were also instructed to concentrate on listening to the stimuli during the presentation.

With the knowledge of previous studies in previous studies, the effective duration (τ_e) of the ACF in α-waves range was thoroughly analyzed. The initial parts (0 dB > $10 \log_{10}[\phi(t)]$ > -5 dB) of the envelope of the normalized ACF in logarithm were employed using a linear regression in order to obtain all the effective duration. The summation interval (N) was set at 2.5 s (Eq. 1. 12).

4. 3 RESULTS

4.3.1 Values of τ_e in α-waves range

For the universality of the experimental identification, the values of τ_e in the α-waves range were examined by three-way analysis of variance (ANOVA) in a 10 x 2 x 2 level classification matrix for the factors of subjects (A ~ J), hemispheric difference (LR), and periods. The results for each pair of periods are indicated in **Table 4. 1**. Significant differences between subjects, and the effects of periods are found in both pairs ($p < 0.001$). The averaged tendencies are illustrated in **Fig. 4. 3**. To further discuss on interference effects between LR and periods, results of an one-way ANOVA on the accumulating values of τ_e with respect to the left and right brain hemispheres for each pair of periods are shown in **Table 4. 2**. It is remarkable that effects of periods are only found in the left hemispheres ($p < 0.001$). The average values of τ_e for every subject in each EEG channel are listed in **Table A-4**.

Furthermore, it is worth noticing that the values of τ_e in α-waves range at periods of 550 ms for each subject from the [550 & 300] ms pairs correlate well with that on the [550 & 1,000] ms pairs (correlation coefficient = 0.94 ($p < 0.001$) in the left hemispheres, indicated in **Fig. 4. 4**).

4.3.2 Individual differences

First, the ratios of the averaged τ_e values at periods of 550 ms to those at periods of 300 ms for each subject are all larger than unities as shown in **Fig. 4. 5** (a) in the left hemispheres. It is different ($p < 0.01$, $F(1, 18) = 10.6$) from that fluctuate in the right hemispheres. Meanwhile, significant differences between the period of 550 ms and 1,000 ms

Table 4.1 Results of three-way ANOVA for global values τ_e in α-waves range, with the factors of subject, periods and hemispheric difference (LR) with ten subjects. The values of τ_e are the respones of the periods changings between two pairs, [550 & 300] and [550 & 1,000] ms.

[300 & 550] ms

Factors	F-ratio	p-value
Subject	27.220	<0.001***
LR	0.492	0.483
Periods	11.086	<0.001***
LR * Periods	4.586	0.033**
Subject * LR	1.366	0.199
Subject * Periods	1.144	0.328

Note: *** p < 0.01, ** p < 0.05, * p < 0.1.

[550 & 1,000] ms

Factors	F-ratio	p-value
Subject	23.679	<0.001***
LR	0.849	0.357
Periods	19.679	<0.001***
LR * Periods	13.916	<0.001***
Subject * LR	2.679	0.004***
Subject * Periods	1.122	0.344

Table 4.2 Results of one-way ANOVA for values of τ_e in α-waves range with respect to the periods effects with ten subjects for left and right hemispheres, respectively.

[300 & 550] ms

Hemisphere	F-ratio	p-value
Left	11.881	<0.001***
Right	0.571	0.450

[550 & 1,000] ms

Hemisphere	F-ratio	p-value
Left	27.937	<0.001***
Right	0.148	0.701

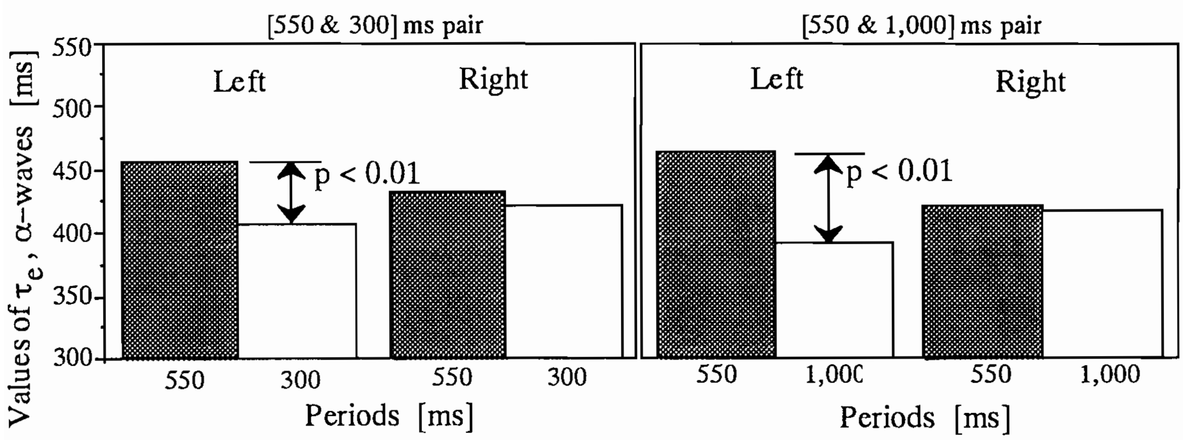


Fig. 4.3 Average tendency of τ_e values in α-waves range which reponsed for changing periods.

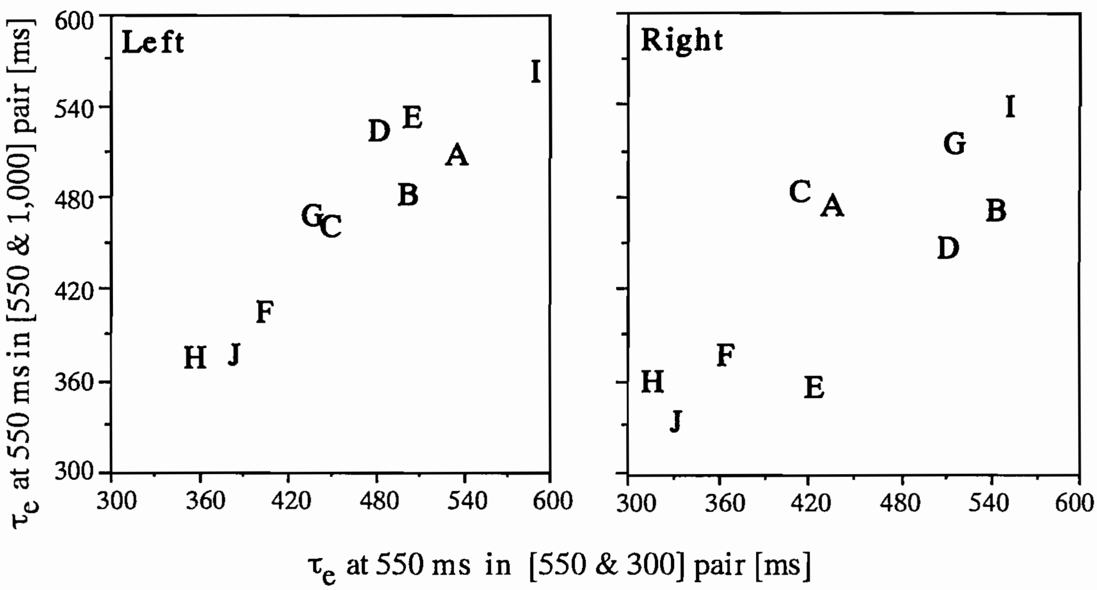


Fig. 4.4 The values of τ_e in α-waves range at periods of 550 ms that were obtained in [550 & 300] pair and [550 & 1,000] pair in the left hemispheres for each subject (A ~ J) show a simple regression between them (correlation coefficient r = 0.94 ($p < 0.001$) in the left hemispheres.

cannot be found as shown in **Fig. 4. 5** (b), left.

In order to discuss individual differences, the ratios ([τ_e (550 ms) / τ_e (1,000 ms)]) of the averaged τ_e values in the left hemispheres for each subject correspond well to the differences in scale values ([SV (550 ms) - SV (1,000 ms)]) of subjective preference are shown in **Fig. 4. 6**. The correlation coefficient r = 0.80 ($p < 0.01$) in the left hemispheres, and r = - 0.12 in the right. However, the correlation is less on the [550 & 300] ms pairs, because almost all consistent preference results were found for all of subjects, and ranges of the ratios of τ_e and the difference of SVs were too small to be correlated.

4. 4 CONCLUSIONS

At the preferred period of 550 ms, values of τ_e in α-waves range are consistently longer than those at period of 300 ms, the difference is found only in the left hemisphere (p <

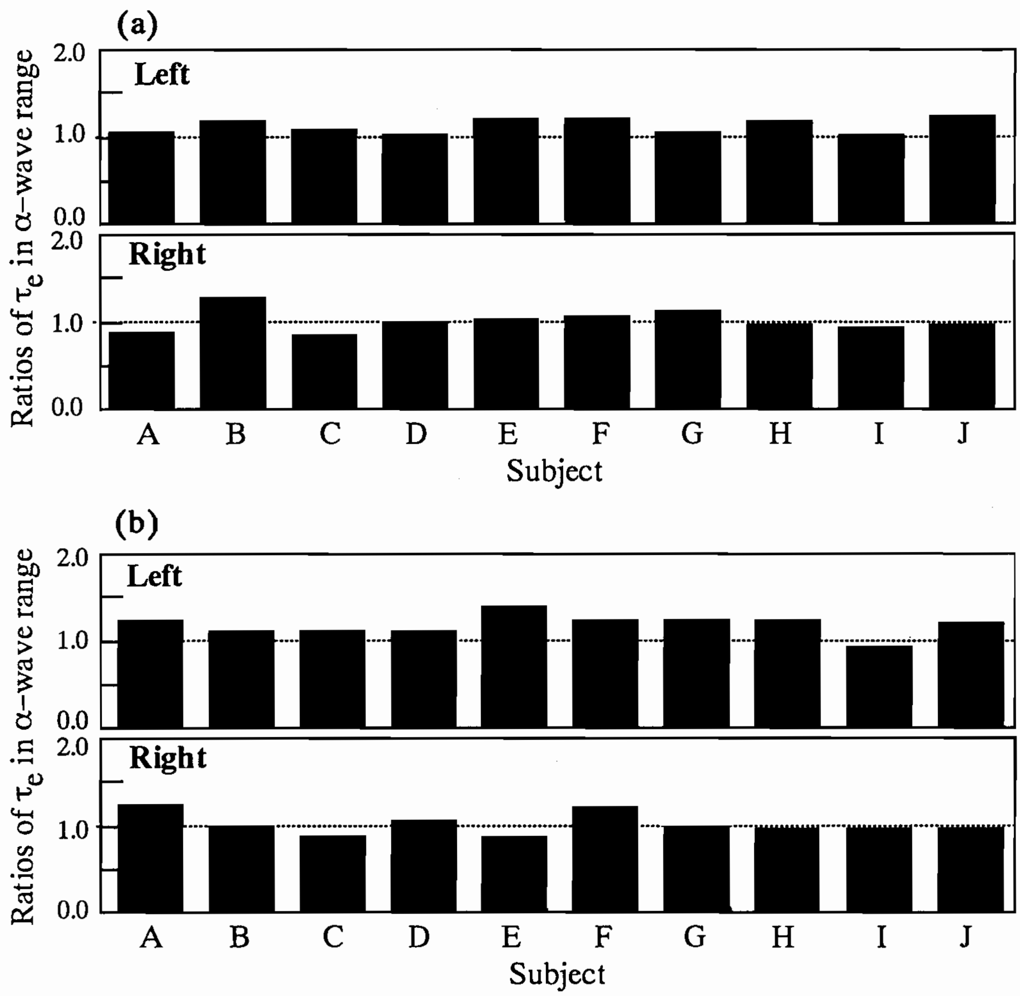
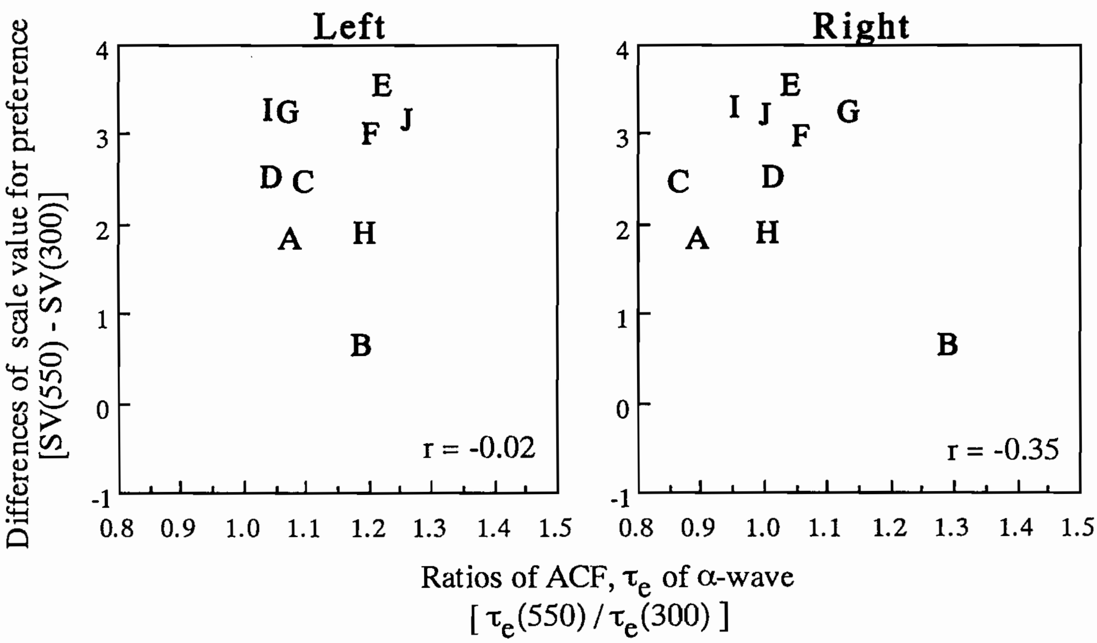


Fig. 4.5 Ratios of ACF, τ_e of α-waves which responded to the periods changes for ten subjects (A ~ J).

Note: (a) [τ_e values at 550 ms] / [τ_e values at 300 ms]; (b) [τ_e values at 550 ms] / [τ_e values at 1,000 ms].

0.001) (**Figs. 4. 3, 4. 5, Table 4. 2**). This tendency at the preferred condition is similar to the results of our previous studies in changing of the delay time of the single reflection (Δt_1) and the subsequence reverberation time (T_{sub}) in a music sound field. Regardless of physical parameters in the sound field, the left hemispheric dominance was based on the temporal point of view. Individual differences of subjective preference between periods at 550 ms and periods at 1,000 ms are significantly related to the ratios of the τ_e values in α-waves range that is obtained only in the left hemisphere (**Fig. 4. 6**, left hemisphere, correlation coefficient = 0.80 ($p < 0.01$)).

[550 & 300] ms



[550 & 1,000] ms

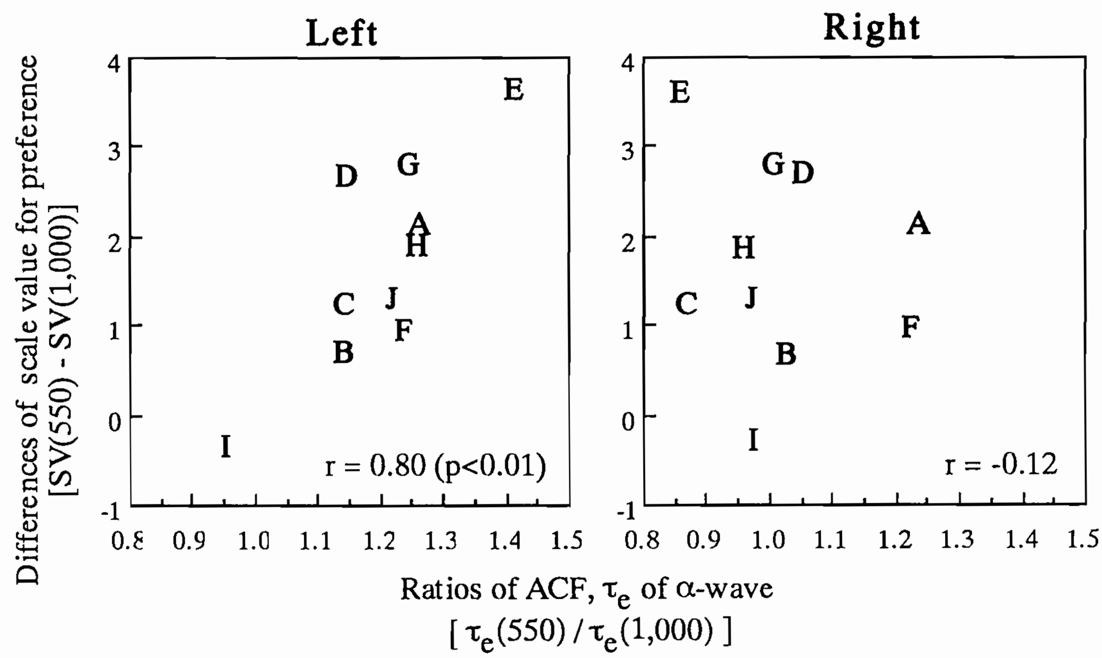


Fig. 4. 6 Relationship between differences of the scale values of preference [SV (550 ms) - SV (1,000 ms)] and ratios of [τ_e (550 ms) / τ_e (1,000 ms)] of α-waves in both hemispheres for each subject (A ~ J). However, the pair of [550 & 300] ms demostrated a low correlation since low individual difference.

4. 5 SUMMARY

It is possible to outspread the time cognition of Δt_1 and T_{sub} to the period by analyzing the τ_e, ACF in the α-wave range in relation to the subjective preference. The physiological method for environmental evaluation is further improved.

CHAPTER V

AUTOCORRELATION FUNCTION OF α-WAVES AND SUBJECTIVE PREFERENCE RESPONDING TO THE VISUAL TEMPO

5.1 INTRODUCTION

5.1.1 Preface

The visual tempo is examined whether or not the continuous brain waves (CBW) well correspond to the subjective preference in situations for changing periods and stimulus target sizes (1°, 5°). First, according to the paired-comparison tests, the most preferred period was found around 0.6 (1°), 0.8 (5°) s. The values of the effective duration (τ_e) of the autocorrelation function (ACF) in α-waves range are independent of spatial information, size. They significantly prolong ($p < 0.01$) as the scale values (SVs) of subjective preference increasing in relation to preferred period on both target sizes. The hemispheric asymmetry was found in [0.2 & 0.8] s pair on size of 5° only ($p < 0.05$). The ratios of the average values τ_e to each subject also well correlate to the differences of SVs in [0.2 & 0.8] s pairs on size of 5° (channel: T5, coefficient of correlation $r = 0.94$ ($p < 0.01$)).

The cross-correlation functions of CBW between two channels were also calculated for observing the dynamic variation of signal transformation on cortex. The results show the lateral dominance in the left hemisphere was confirmed.

5.1.2 Review

i) The autocorrelation function of CBW in the α-wave range

A number of studies has comfirmed that the effective duration (τ_e) of autocorrelation function (ACF), in α-waves range of continuous brain waves (CBW) well correlates to the scale values (SVs) of subjective preference in changing of the delay time of the single reflection (Δt_1), the subsequence reverberation time (T_{sub}) or the noise-burst periods for a sound field (Ando & Chen [31]; Chen & Ando [32]; Chen, Ryugo & Ando [33]). Typical findings have included the following:

(1) Cerebral asymmetry leads a theory of lateral domination for specialized physical informations in a sound field. Ando [1]) asserts that the physical factors of a sound field effectively present the temporal and spatial characteristics, respectively. It is found that the values of τ_e significantly prolong in left hemisphere in case that the temporal factors varied, prolongs in the right hemisphere in case that the spatial factor varied (Nishio & Ando [34]).

(2) The values of τ_e significantly prolong as the scale values of subjective preference increasing pertaining to the physical factor changing in a sound field.

(3) The ratios of the values of τ_e well correlate to the differences of SVs, subjective preference in left hemisphere in the situations where stated in (1) and (2).

ii) The standpoints of visual tempo

In a function of the time cognitive activities in periods, Mishima [27][28] investigated the "mental tempo" by using flickering lamp, metronome, and so on. He found inconsistency in their tempo between stimuli. The most preferred period was centered at 550 ms in an arrangement of 400, 550, 700 ms increments by 10 ms noise-burst in previous study. For visual consciousness in periodic discrimination, there are many reports indicating the different sensitivity in distinct position of retina (Hecht and Verrijp [35], Mowbray and Gebhard [36], Suzanne and Douglas [37], ... edc.). Mo and Michalski [38] found that increasing the size of a briefly flashed small circle (9 mm) led to an increase in its apparent duration. Tyler [39] reported that the periphery can detect higher rates of flicker than the fovea for stimuli that contain significant low-spatial-frequency information.

In the present study, blink-spots are varied in periods, however, the stimuli are encoded the spatial information by changing target size on 1° and 5°(including 1° part) circles. In order to observe the relationship between SVs of subjective preference and τ_e of ACF, in α-waves range of CBW, the preferred tempo is first examined by paired-comparison test. Then, a series of brain waves recordings for ACF analyses are empolyed as the results corresponding with SVs.

However, the values of τ_e of ACF become weaker for examining the cerebral specialization for the universal identification in conventional studies (**Table 5.1**). In present study, CBW are also examined using a cross-correlation analyses to observe a temporal

Table 5.1 Results of the three-way ANOVA for global values of τ_e in the α–wave range with the sources of subjects, the effect of varied factor and hemispheric difference (LR) in our serial studies.

Factor	Δt_1 (35 & 245) ms	T_{sub} (0.2 & 1.2) s	T_{sub} (1.2 & 6.4) s	Noise tempo (0.3 & 0.55) s	Noise tempo (0.55 & 1.0) s	Visual tempo (1° target) (0.2 & 0.6) s	Visual tempo (1° target) (0.6 & 3.2) s
Effects	<0.05	<0.05	---	<0.001	<0.001	<0.05	---
LR(T3,T4)	---	---	---	---	---	---	---
Subjects	<0.001	<0.001	<0.001	<0.001	<0.001	<0.005	---

imformation between T3-T4 and T5-T6 channels. Since the cortical aeras are supposed to be correlated to the "higher" integration that correspond to the visual preference coded in temporal stimuli moving across both hemispheric fields. The maximum cross-correlogram of left- or right recordings ($|\phi_{LR}(\tau)|_{max}$) indicates a primary area for the visual information was measured.

5. 2 METHODOLOGY

5.2.1 Stimuli and subjects

Sinusoidal blink-spot were produced by cathode-ray tubes (CRT, frame rate: 30 fps). To keep away from dazzling and strain in dark- and light adaptation, the stimuli were sinusoidally managed by computer (**Fig. 5. 1**). CRT were placed in a dark anehoic chamber in the front of subject's eyes position in a distance of 1 m apart to keep foveal fixation (in natural binocular) with the target on CRT within dark surrounding (**Fig. 5. 1**). Periods begin at sinusoidal peak to next in five logarithmically increasing intervals, where 0.6 s is the knowledge of previous study. Thus, they were 0.2, 0.4, 0.6, 0.8, 1.6 or 3.2 s (0.3 ~ 5.0 Hz) with identical total input energy for equal delectability (Zacks [40]), among a time sequential span approximate 5.1 s.

The subjects (A ~ G) all had normal or corrected visual acuity and were all right-

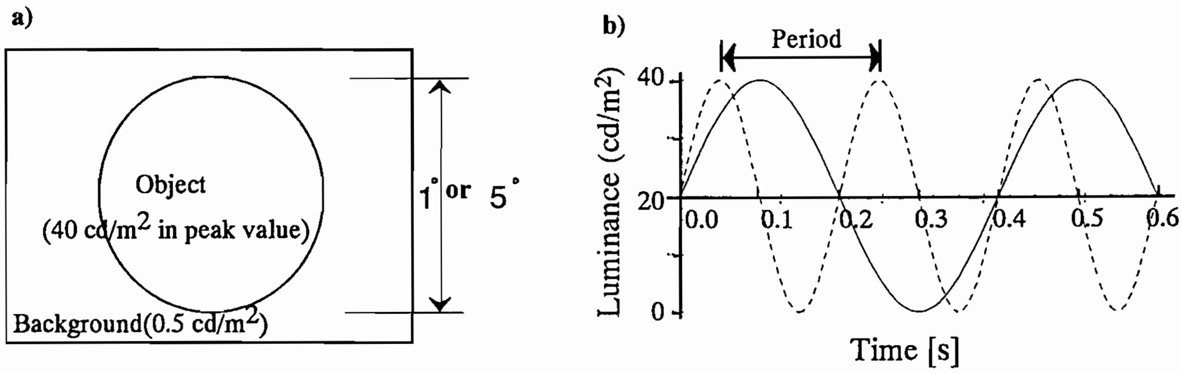


Fig. 5. 1 The preferred tempo test field (a) was moderated by sinusoidally managed (b) in a steady dark surrounding on CRT display. Periods began at peak value to the next from 0.2 s to 3.2 s.

Note: a) Cathode-ray tubes (CRT, 40° x 60°).

b) Moderated sinusoidal light blink.

handed (self-reported). Their ages ranged from 22 to 33 years old (M = 24.3, SD = 3.7).

5.2.2 Subjective preference tests

Depending on paired-comparison method [1], the preference scores of all seven subjects were evaluated for each size of target. Subjects reported the preferred tempo in a pair they preferred to follow, then they pushed a button to record their responses. The scale values (SVs) of the subjective judgement of each subject was calculated according to Case V of Thurstone's theory [4], and the model was reconfirmed by the goodness of fit (Mosteller [20]). The results show the SVs' model had a good match between fitted values and the observed values (χ^2 = 16.3(1°), 12.3(5°) < χ^2_{10} (0.05) = 18.3). As indicated in **Fig. 5. 2**, the most preferred period was centered at 0.6 s among seven subjects for the target of 1°, but 0.8 s for 5°.

5.2.3 Recordings and Analyses of the CBW

In order to find the significant effects of tempo on CBW, the most preferred period, 0.6, 0.8 s, and the least preferred period, 0.2, 3.2 s were selected, Four kinds (indicated in **Table 5. 2**) of pairs were successively presented every ten times (one session) with a 2.0 s

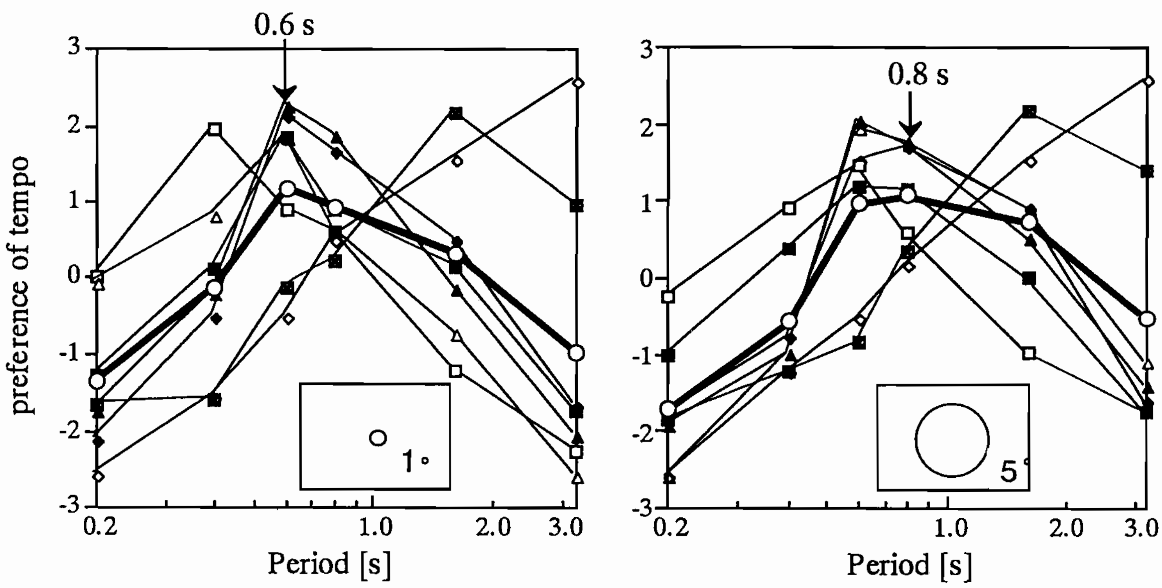


Fig. 5. 2 Results of the scale values of the selective preference obtained by the paired-comparison judgments with seven subjects (A ~ G). The average preferred period is longer on the target size of 5° than 1°.

Note: Symbol illustration

Table 5. 2 Condition of brain waves' recordings. The stimuli pairs were presented in ten times running for two target sizes to each subject, and recorded same four EEG channels simultaneously.

Target size	Periods in running pairs [s]	EEG channel
1°	(0.2 & 0.6), (0.6 & 3.2) s	T3, T4, T5, T6
5°	(0.2 & 0.8), (0.8 & 3.2) s	T3, T4, T5, T6

repetitive interval and target changing size each time between sessions.

i) Autocorrelation analyses

Owing to the hypothsis of that signals in brain are managed by an autocorrelative process (see Section 1.2 and 1.3). The CBW were recorded simultaneously from T3, T5, T4 and T6 by means of the international 10 / 20 placement system (see **APPENDIX A**). The CBW signals were analyzed after passing through a digital filter (cut-off slope: 140 dB/oct.), 8 ~ 13 Hz (α-wave range), with sampling at a rate of 100 Hz. Then, the effective duration (τ_e) of the ACF was thoroughly analyzed. The initial parts (0 dB > $10 \log_{10}[\phi(\tau)]$ > - 5 dB) of the envelope of the normalized ACF in logarithm were employed using linear regression in order to obtain all the effective duration. The summation intervals (N) were all set at 2.5 s (substituted in Eq. 2.3).

ii) Cross-correaltion analyses

A hypothsis of the potntial flow, which encodes in the visual information processing was observed by cross-correlation analyses. The correlation values are calculated as below

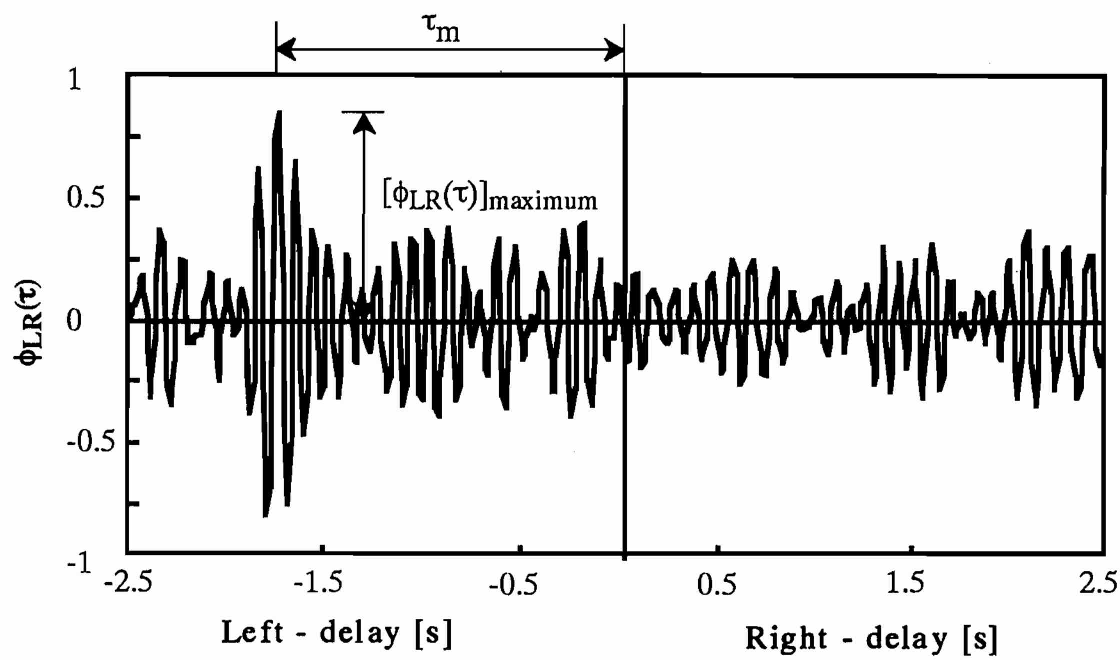


Fig. 5. 3 Analysis of normalized cross-correlation function of α-waves between EEG channels remarkablely obtains a maximum value and a delay time (τ_m) at of that. The negative position of τ_m means the visual evoked potential flows toward to the left cerebral cortex is faster than those to the right.

$$\phi_{LR}(\tau) = \frac{\sum_{n=0}^{N-1} x_L(n) x_R(n-\tau)}{\sqrt{\sum_{n=0}^{N-1} x_L{}^2(n) x_R{}^2(n)}} \tag{5.1}$$

Where N is an interval for a 2.5 s linear sum of CBW in α-waves range from the stimulus setoff for each channel. Then, the maximum values of each cross-correlation function ($[\phi_{LR}(\tau)]_{max}$) were assumed to derive a delay time (τ_m) to prvide the dynamic position were caculated (**Fig. 5. 3**).

5. 3 RESULTS

5.3.1 Values of τ_e in the α-wave range

For the universality of the experimental identification, the values of τ_e in the α-wave range were examined by three-way analyses of variances (ANOVAs) in 7 x 2 x 2 level classification matrixes for the factors of subjects (A ~ G), hemispheric difference (T3- T4 or T5- T6), and periods (0.2& 0.6, 0.6& 3.2, 0.2& 0.8 or 0.8& 3.2 s). The results on both target size for 8 classes are indicated in **Table 5. 3.** Significant differences between subjects were only found in pair of [0.2 & 0.6] and [0.2 & 0.8] s ($p < 0.005$, $p < 0.001$) in T3- T4 channels. The effects of periods are found in pair of [0.2 & 0.6] s in both pairs ($p < 0.05$, $p < 0.001$) on the target size of 1 °, however, [0.2 & 0.8] s in T3- T4 ($p < 0.01$), and [0.8 & 3.2] s in T5- T6 ($p < 0.005$) on the target size of 5 °. The cerebral asymmetry are found only on the target size of 5 ° for [0.2 & 0.8] s in T3- T4 ($p < 0.05$). To further discuss on interference effects between LR and periods, results of an one-way ANOVA on the accumulating values of τ_e derived from the left- and right brain hemispheres for each pair of periods are shown in **Table 5. 4**. And the averaged tendencies are illustrated under the significant difference examination. It is remarkable that effects of periods are only found in the left hemispheres on the target size of 5 ° (see an example shown in **Fig. 5. 4**).

5.3.2 The correlation between SVs and values of τ_e

Table 5. 3 Results of three-way ANOVA for global values τ_e in the α-wave range, with the factors of subject, periods and hemispheric difference (LR) with seven subjects. The values of τ_e are the responses of the periods changing between two pairs, [0.2 & 0.6], [0.6 & 3.2] s and [0.2 & 0.8], [0.8 & 3.2] s for target size of 1° and 5°, respectively.

Target size	1°				5°			
Channel	Period [s]	Subject	LR	Period	Period [s]	Subject	LR	Period
T3 - T4	[0.2 & 0.6]	$p < 0.005$	-	$p < 0.05$	[0.2 & 0.8]	$p < 0.001$	$p < 0.05$	$p < 0.01$
	[0.6 & 3.2]	-	-	-	[0.8 & 3.2]	-	-	-
T5 - T6	[0.2 & 0.6]	-	-	$p < 0.001$	[0.2 & 0.8]	-	-	-
	[0.6 & 3.2]	-	-	-	[0.8 & 3.2]	-	-	$p < 0.005$

Table 5. 4 Results of one-way ANOVA for values of τ_e in the α-wave range with respect to the periods effects with seven subjects for left and right hemispheres, respectively on target size of 1° and 5°. Below the significant difference examination, averaging tendencies were indicated.

Target size	1°		5°	
Period[s]	[0.2 & 0.6]	[0.6 & 3.2]	[0.2 & 0.8]	[0.8 & 3.2]
L. H. (T3)	$\tau_e(0.2) < \tau_e(0.6)$***	$\tau_e(0.6) > \tau_e(3.2)$	$\tau_e(0.2) < \tau_e(0.8)$***	$\tau_e(0.8) > \tau_e(3.2)$
R. H. (T4)	$\tau_e(0.2) \leq \tau_e(0.6)$	$\tau_e(0.6) < \tau_e(3.2)$***	$\tau_e(0.2) \leq \tau_e(0.8)$	$\tau_e(0.8) > \tau_e(3.2)$
L. H. (T5)	$\tau_e(0.2) < \tau_e(0.6)$***	$\tau_e(0.6) > \tau_e(3.2)$***	$\tau_e(0.2) < \tau_e(0.8)$	$\tau_e(0.8) > \tau_e(3.2)$***
R. H. (T6)	$\tau_e(0.2) < \tau_e(0.6)$**	$\tau_e(0.6) < \tau_e(3.2)$	$\tau_e(0.2) \geq \tau_e(0.8)$	$\tau_e(0.8) > \tau_e(3.2)$

Note: *** $p < 0.01$, ** $p < 0.05$. L. H. Left hemisphere, R. H. Right hemisphere.

As the knowledge of the previous studies, the ratios (indicated in **Table. 5. 5**) of the averaged τ_e values in the left- and right hemispheres (T3-T4, T5-T6) for each subject are calculated to compare with the differences in scale values of subjective preference. The correlation coefficient is greatest in T5 for [0.8 & 3.2] s pair ($r = 0.94$ ($p < 0.01$)) .

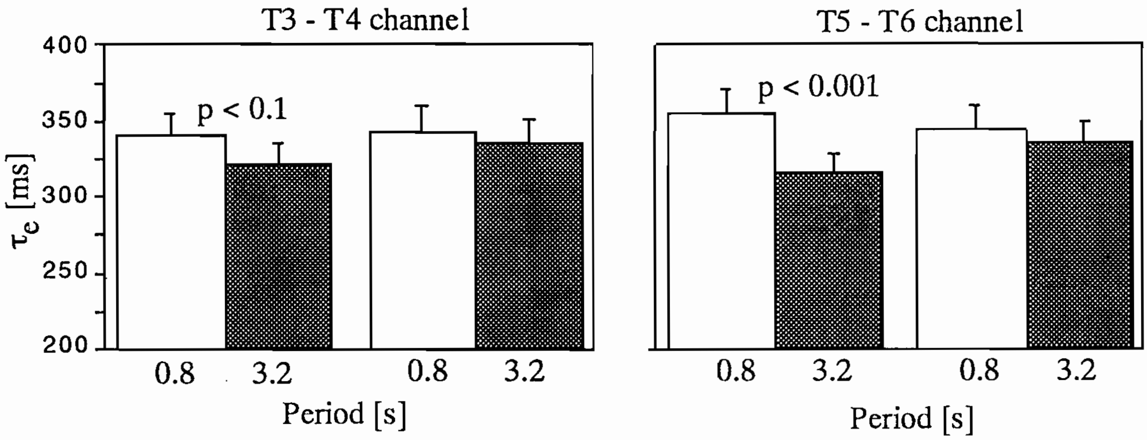


Fig. 5. 4 The averaging tendencies of the values of τ_e of ACF, in α-waves range show significantly longer at preferred period at 0.8 s as referring to 3.2 s on the target size of 5 °.

Table 5. 5 Relationship between differences of the scale values of preference (i.e., SV (0.6 s) - SV (0.2 s)) and ratios of (i.e., τ_e (0.6 s) / τ_e (0.2 s)) of α-waves in left- and right hemispheres (L. H. : T3- T5, R. H. : T4- T6) for average values of each subject (A ~ G) were obtained. It shows a greatest correlation ($r = 0.94$ ($p < 0.01$)) in T5 in respect to period = 0.8 s as comparing with 3.2 s on the target size of 5 °.

Target size	1°				5°			
	[SV (0.6 s) - SV (0.2 s)] vs τ_e (0.6 s) / τ_e (0.2 s)				[SV (0.8 s) - SV (0.2 s)] vs τ_e (0.8 s) / τ_e (0.2 s)			
L. H.	**T3**	-0.16	**T5**	-0.29	**T3**	-0.31	**T5**	0.51
R. H.	**T4**	-0.64	**T6**	0.37	**T4**	0.66	**T6**	-0.55
	[SV (0.6 s) - SV (3.2 s)] vs τ_e (0.6 s) / τ_e (3.2 s)				[SV (0.8 s) - SV (3.2 s)] vs τ_e (0.8 s) / τ_e (3.2 s)			
L. H.	**T3**	0.60	**T5**	0.75**	**T3**	0.75**	**T5**	0.94***
R. H.	**T4**	0.66	**T6**	-0.01	**T4**	0.38	**T6**	-0.12

Note: *** p < 0.01, ** p < 0.05.

5.3.3 The maximum values of cross-correlation for lateral dominance hypothsis

For the consideration of the lateral dominance in temporal management, the maximum cross-correlation were analyzed between either two channels (T3, T4, T5 and T6) of CBW in the α-wave range that corresponded to the period of 0.2 and 3.2 s referring to 0.6 or 0.8 s at the target of 1°, or 5°. The maximum correlation ($r > 0.5$), $|\phi_{LR}(\tau)|_{max}$ between T3- T4 were indecated by frequency distribution in **Fig. 5. 5a** and **Fig. 5. 5b** as a sample. The other results were showed in the **APPENDIX F**. They demostrate that, the probabilities for the T3-delay are greater than that for T4-delay. And the probabilities for the period = 3.2 s show a peak value at 1.6 s of delay, they more clearly appear in T5-delay than that in T3-delay in T3-T5 correlation (see **APPENDIX F**). However, it is to be regretted that fewer data could be observed a matter of detail.

5. 4 CONCLUSIONS AND DISCUSSION

The scale values of subjective preference for preferred tempo significantly varied ($p < 0.05$) in the case that blink-spot were changed the target size (**Fig. 5. 2**). However, the values of τ_e of ACF, in the α-wave range are independent of size changing for effects of period. At the preferred period of 0.6 and 0.8 s, values of τ_e are consistently longer than those at period of 0.2 s, only in the left hemisphere (T3, T5) (**Table 5. 3**). This tendency at the preferred condition is similar to the results of our previous studies in changing of Δt_1, T_{sub} or noise-burst tempo in a sound field. Individual differences of subjective preference between periods at 0.6, 0.8 s and periods at 0.2, 3.2 s are significantly related to the ratios of the τ_e values, which are clearly obtained in the left hemisphere, specially, in T5 for the target size of 5°(**Table. 5. 5**, left hemisphere, correlation coefficient = 0.94 ($p < 0.01$)).

The result of $|\phi_{LR}(\tau)|_{max}$ shows that visual information significantly moves cross from left to right in T3- T4 temporal codings (**Fig. 5.5a** and **Fig. 5. 5b**).

5. 5 SUMMARY

(1). An improvement of visual phenomenon was clearly verified by the correlation between subjective preference and the autocorrelation function of CBW in the α-wave range.

(2). Besides the correlation was consistently found, the hemispheric specialization also reconfirmed by analyzing the cross-correlation function. A signal propagation

1°

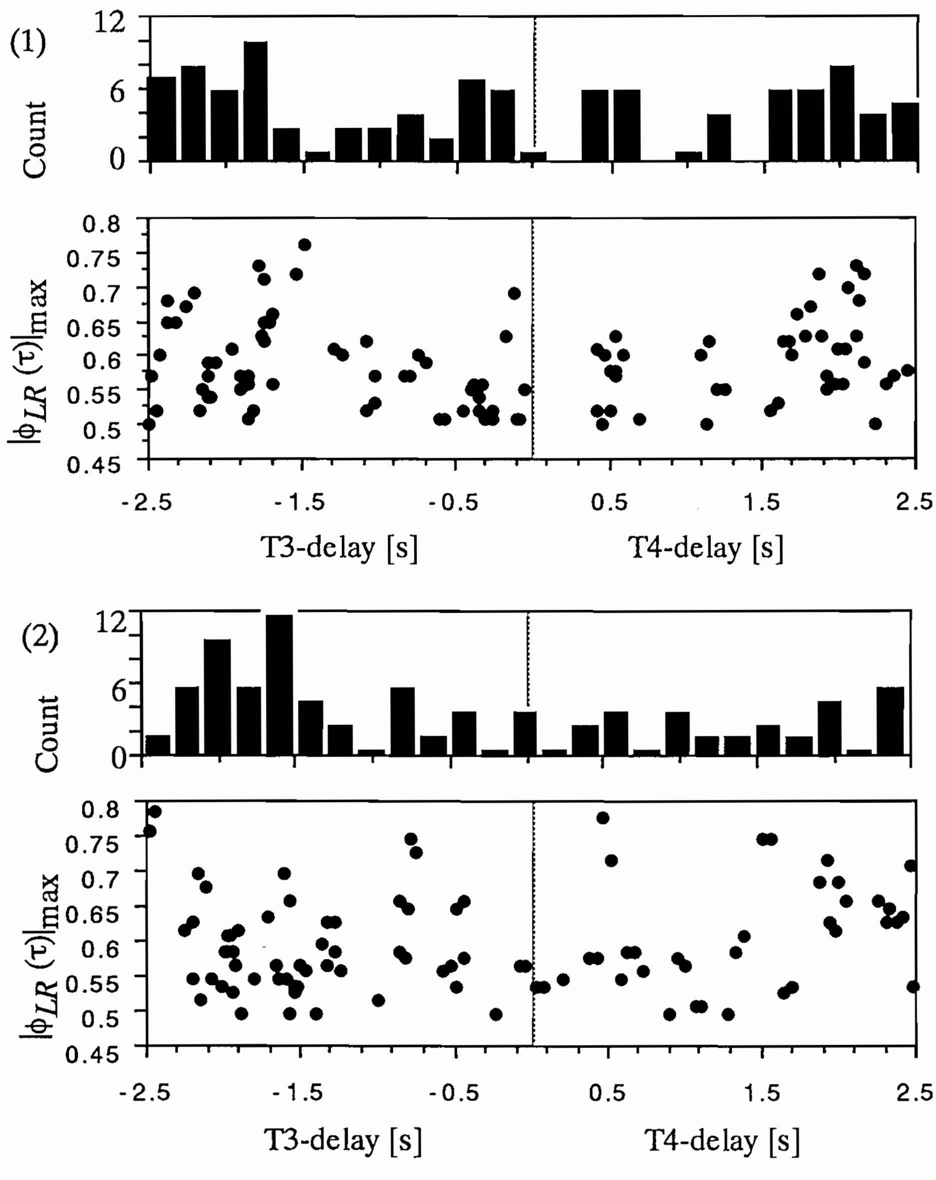


Fig. 5. 5a. The values of $|\phi_{LR}(\tau)|_{max}$ in between T3 and T4 channels were indecated in frequency distribution, and the scatter diagram showed below as references. They are the responses of changed period = 0.2 s (1) to 3.2 s (2), both of them were presented referring to period = 0.8 s in a target of 1°.

5 °

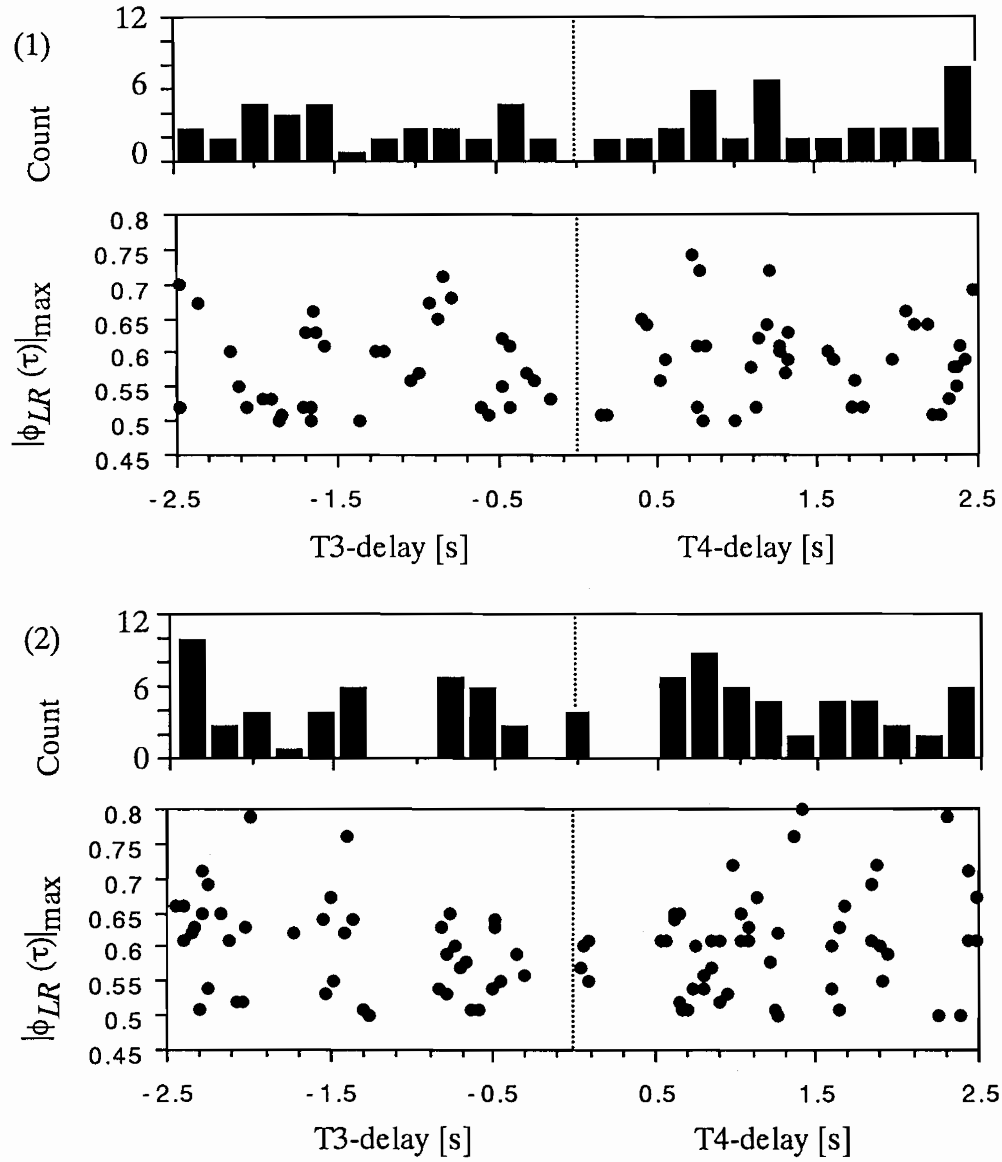


Fig. 5. 5b. The values of $|\phi_{LR}(\tau)|_{max}$ in between T3 and T4 channels were indecated in frequency distribution, and the scatter diagram showed below as references. They are the responses of changed period = 0.2 s (1) to 3.2 s (2), both of them were presented referring to period = 0.8 s in a target of 5°.

phenomenon on the horizontal cortex was idnetified by the temporal coding management.

CHAPTER VI

DYNAMIC ANALYSES OF BRAIN WAVES: CROSS-CORREALTION FUNCTION OF α-WAVES BETWEEN EEG CHANNELS

6. 1 INTRODUCTION

6.1.1 Preface

As found in previous chapters, autocorrelation is weak for examining an universally identifiable cerebral specialization in conventional studies (**Table 5.1**). In the present study, CBW is also examined using cross-correlation analyses (Eq. 5.1) to measure delay times between EEG channels. The maximum cross-correlogram of left or right signals ($|\phi_{LR}(\tau)|_{max}$) demonstrates a primary channel for temporal information management (illustrated in **Fig. 5. 3**). The data is the CBW recordings in the α-wave range also employed in chapter II and III. They are the responses to changing the initial delay of the single reflection (Δt_1) and the subsequence reverberation time (T_{sub}) in a music sound field. The results show a consistant deviation toward to the left-delay (T3-delay) at a delay of approximately 100 ms.

6.1.2 Cross-correlation analysis

There are few studies of measuring the signal delay between cortical aeras by using temporal correlation analyses of neuronal activity. Depending on the assumptive processing in the auditory pathway (**Fig. 1.5**), Ando, Yamamoto, Nagamatsu and Kang [39] found a possible interaural cross-correlation mechanism at the inferior colliculus by measuring auditory brainstem responses in a short interval about 10 ms. This suggests we should investigate the temporal coding in the auditory cortex by recording CBW. Even though it may serve to research the correspondances of complex factors at a higher-order than the auditory primary cortex, the cortex is expected to enable the observation the composition of synchronized mental states.

Here, we should expend the Eq. 1.1 to follow a binaural criterion, which was discussed in the Section 1.2.1. Then, the interaural cross-correlation function (ICF) is defined by

$$\Phi_{LR}(\tau) = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{+T} f_L(t) f_R(t+\tau) dt . \qquad (6.1)$$

The normalized ICF is defined as Eq. 5.1. It was employed here for detecting the responses between two hemispheres (primary auditory field), a product of neural activity aroused by $f_{L,R}(t)$, the presures at the two ears. The definition of the maximum values of normalized ICF ($|\phi_{LR}(\tau)|_{max}$) and its position (τ_m) between the left and right delay is illustrated in **Fig. 5.3.**

6.1.3 Aim of this study

The results for τ_m will demonstrate the dominant area (left or right) of the signal management in the cortex, and the observed interaction was assumed to be the result in defferent neuron transformational path of specificity. It reconfirms the hemispheric difference theory discussed in previous chapters (see Section 5.1.2, **Table 5.1**).

6. 2 METHODOLOGY

The data from two of our studies (Ando and Chen [31], Chen and Ando [32]) have indicated that the effective duration (τ_e) of ACF, in the α-wave range of CBW, well correlates with the scale values (SVs) of subjective preference, for changing the delay time of the single reflection (Δt_1) and the subsequence reverberation time (T_{sub}). The conditions for all responses to changes in Δt_1 and T_{sub} are listed in **Table 6.1**.

According to the assumption of signal delay between left and right hemispheres stated above, the positions of $|\phi_{LR}(\tau)|_{max}$, τ_m , were all calculated. The responses of left and right hemispheres are derived from EEG channels T3 and T4, respectivly. The signals of x_L and x_R in the Eq. 5. 1, the 2.5 s linear sums for autocorrelation at $\tau = 0$, was used to normalize that of the cross-correlation for all CBW's data.

Table 6.1 The condition of EEG recordings on the T3 and T4 corresponding to changing Δt_1, T_{sub} and IACC, all of stimuli were about 5 s.

Factors	Range of changed	Numbers of subjects
Initial delay time of single reflection (Δt_1)	35 ms, 245 ms	11
Subsequence reerberation time (T_{sub})	0.2 s, 1.2 s 1.2 s, 6.4 s	10
Magnitude of interaural cross-correlation (IACC)	0.95, 0.3	5

Note: The values of above are all the setting conditions.

6. 3 RESULTS

According to the previous chapters, the maximum correlation, $|\phi_{LR}(\tau)|_{max}$ was examined in the range of 0.5 to1.0. The analyses of τ_m for all EEG recordings were indicated by frequency distribution, and the count numbers show the tendency of delay positions. It demonstrates a dominant direction of temporal information processing corresponding to the varied Δt_1 or T_{sub}. As illustrated in **Fig. 6. 1**, both Δt_1 = 35 ms and 245 ms have T3-delay deviation at approximately 100 ms. The results of varied T_{sub} show the consistent T3-delay, but not so significantly seen (**Fig. 6. 2a and Fig. 6. 2b**).

6. 4 CONCLUSIONS

The values of τ_m, the position of $|\phi_{LR}(\tau)|_{max}$ of the normalized ICF in the α-wave range reconfirmed: 1) the hemispheric specialization of temporal information processing proposed by Ando[1] for the independent factors in music sound fields; 2) for reference, Nishio and Ando [34] found a consistent T4-delay as the magnitude of interaural cross-correlation (IACC) was changed from 0.3 to 0.95, which is a spatial standard in a music sound field, **Fig. 6.3** indicats the global results of changing IACC for 5 subjects in the T4- T3, T4- C3, T4- C4, T4- Cz correlations; 3) the parallel distributed networks in primary auditory pathways (**Fig. 1.5**) were reconfirmed, the association temporal cortices, T3 and T4, a higher correlation arrived in a short delay (about 0.1 s for changing Δt_1) between them.

6. 5 SUMMARY

(1) The analyses of cross-correlation in the α-wave range of CBW is an effective method for detecting the cerebral hemispheric specificity.

(2) The model in **Fig. 1.5** proves that the parallel system in auditory pathways between left and right cerebral hemispheres is composed of correlation processing.

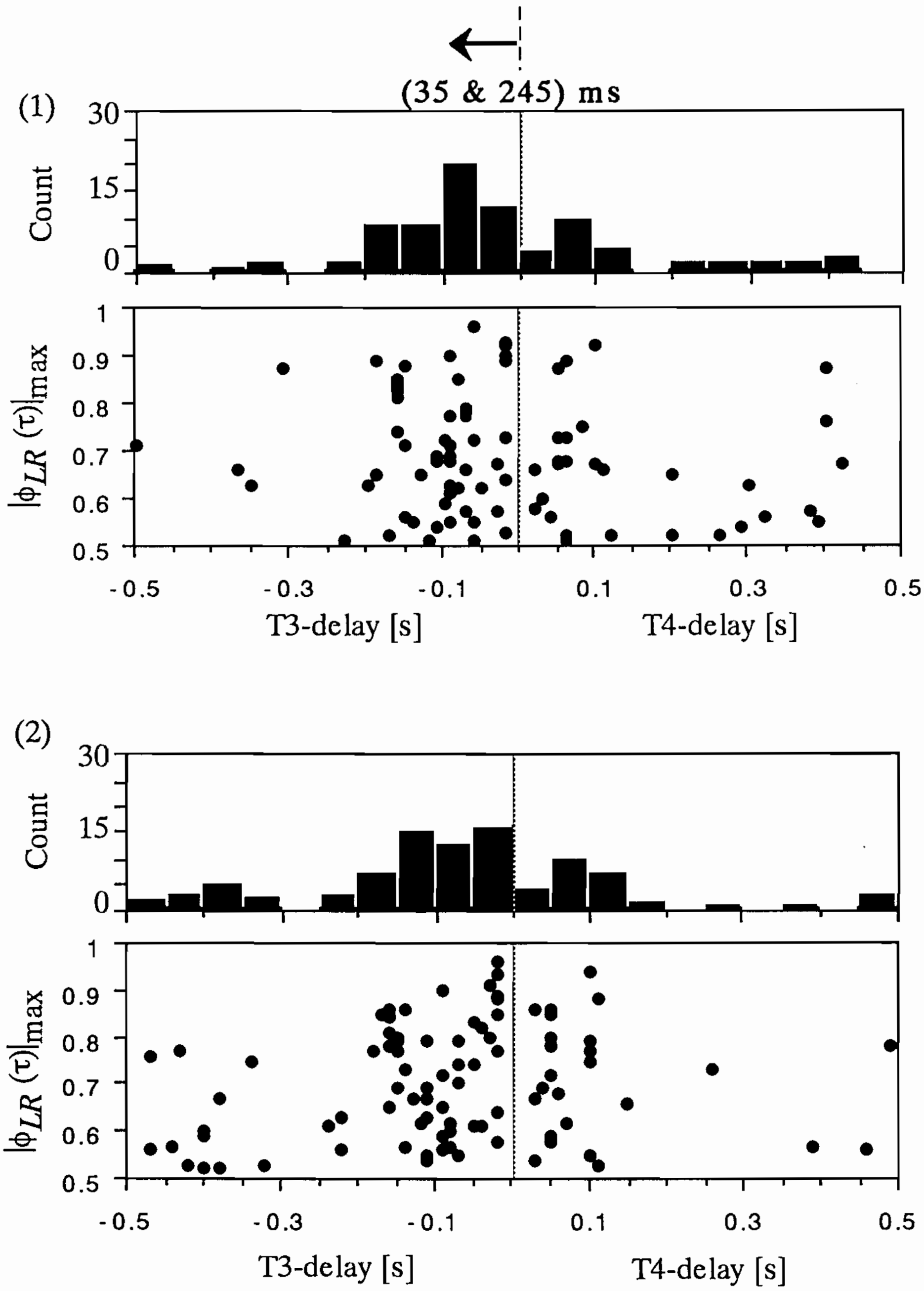


Fig. 6. 1 The values of $|\phi_{LR}(\tau)|_{max}$ were illustrated in frequency distribution, and the scatter diagram also showed below as reference. They are the responses of changed Δt_1 = 35 ms (1) to 245 ms (2).

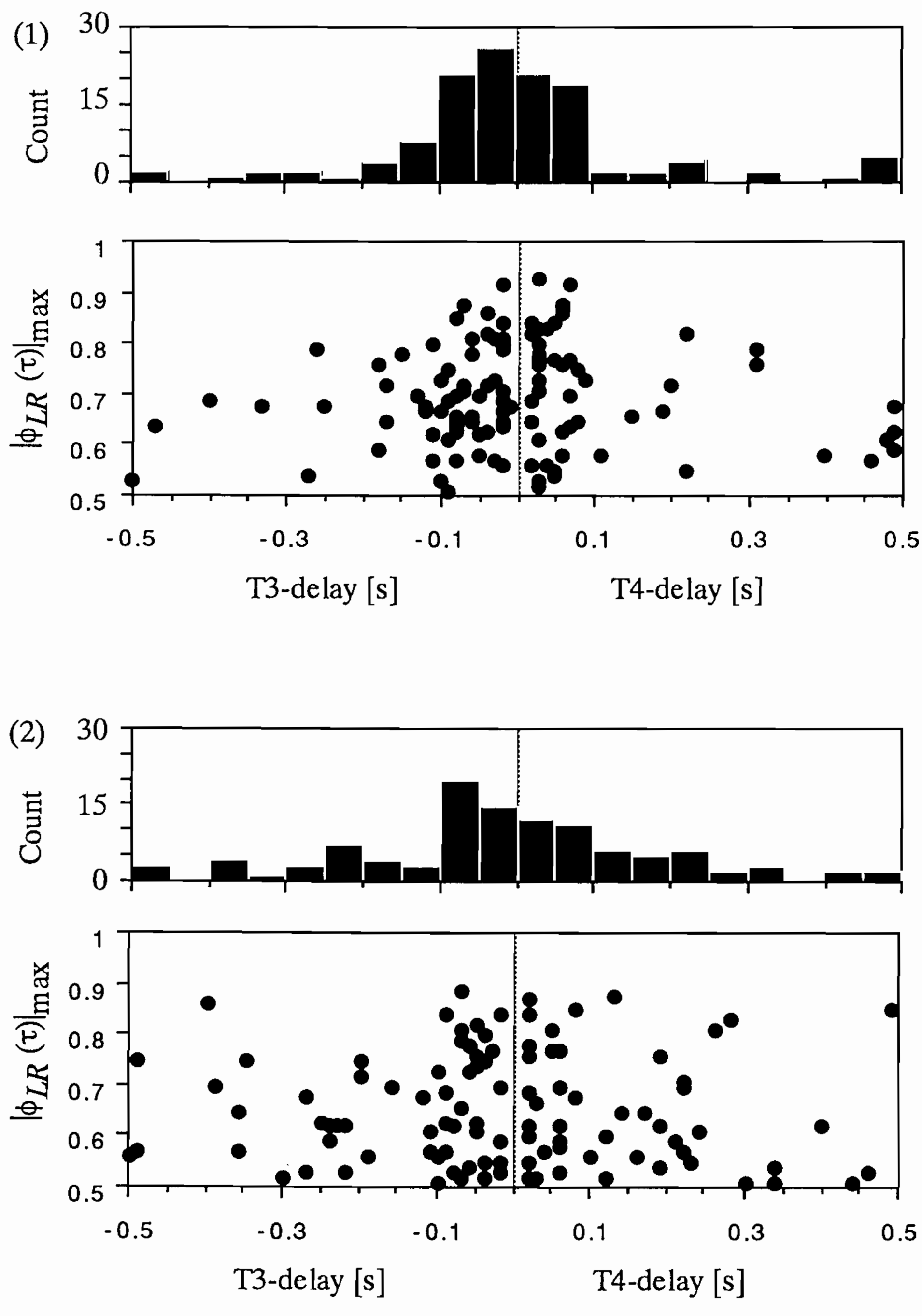


Fig. 6. 2a The values of $|\phi_{LR}(\tau)|_{max}$ were illustrated in frequency distribution, and the scatter diagram also showed below as reference. They are the responses of changed T_{sub} = 0.2 s (1) to 1.2 s (2).

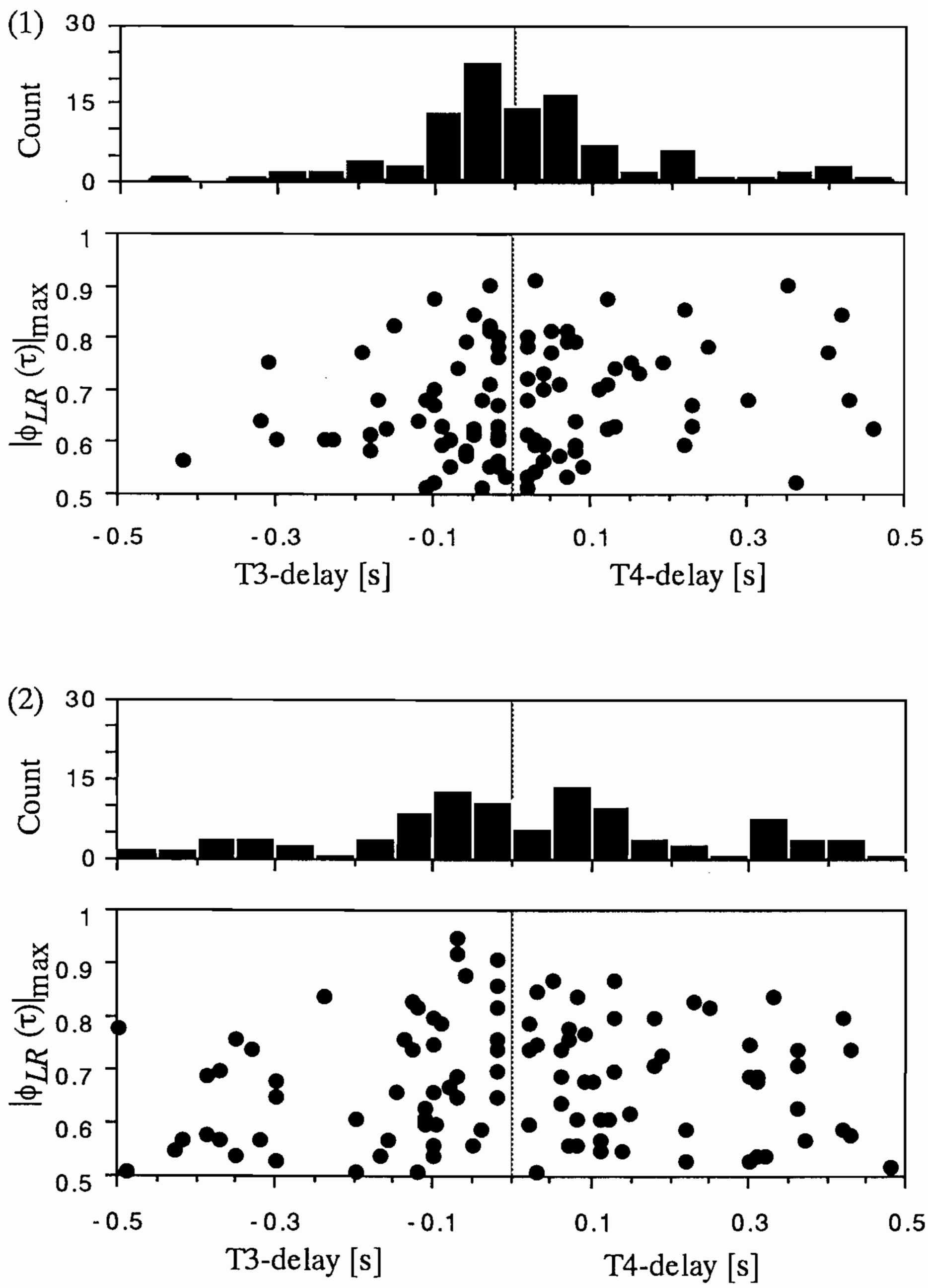


Fig. 6. 2b The values of $|\phi_{LR}(\tau)|_{max}$ were illustrated in frequency distribution, and the scatter diagram also showed below as reference. They are the responses of changed T_{sub} = 1.2 s (1) to 6.4 s (2).

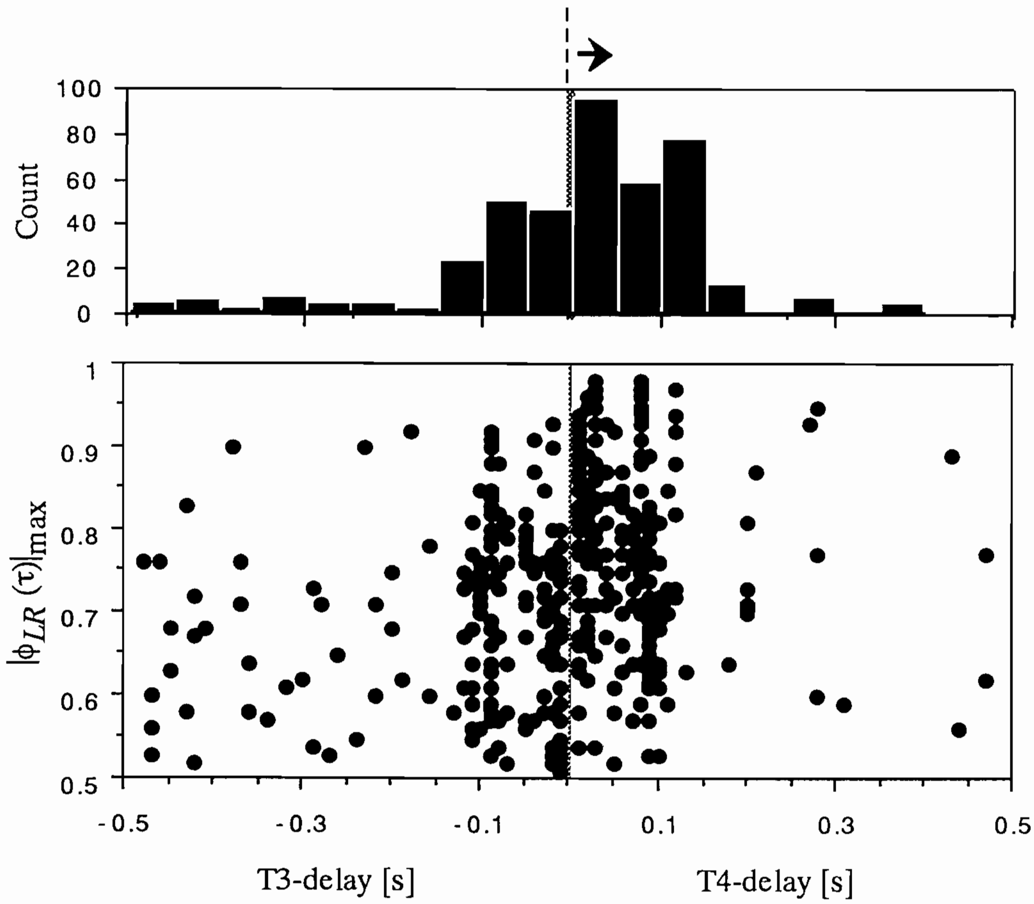


Fig. 6. 3 The values of $|\phi_{LR}(\tau)|_{max}$ were illustrated in frequency distribution, and thescatter diagram also showed below as reference. They are the responses of changed IACC =0.95 to 0.3 in global.

CHAPTER VII

SUMMARY AND CONCLUSIONS

7. 1 SUMMARY AND CONCLUSIONS OF THE STUDIES

This study made steps towards closing the gap between subjective evaluation of one's surroundings and objective measurement of brain activities. They involved the psychoacoustic, subjective tempo in the auditory and visual systems. First, in the case of designing a concert hall, it is possible to observe CBW with a simulation by using an autocorrelator in a monoaural pathway. Then, the preferred tempo, a standard of time for the interval cognition of a work was extended, which can be well connected in many temporal preference. For example, the study of designing display, an important implement in our communication with information media, visual adaption requires good temporal charactertistics, it can be evaluated by brain activities. In this study, visual tempo was investigated, and a preferred blinking period is also interpreted by managing autocorrelation. Finally, for the purpose of hemispheric specialization, the data were analyzed again. A standard model for time planning in relation to neural parallel transformations in the auditory pathway was also found by cross-correlation analysis.

Chapter I stated an important theory of subjective judgement, but outwith comprehensive application in normal surroundings of human's living. With regard to previous studies of auditory evoked potential, we considered a comparative long recordings in α-waves range of CBW may support a high correlation with preference.

Chapter II optimized a stimulation system (paired-comparison system) and the analyses of ACF of brain waves in the α-wave range correlates well to the subjective preference in a 2.5 s segment who considers the "psychological present".

Then, the effective duration of ACF (τ_e) of CBW in the α-wave range corresponds efficiently to the subjective preference, and prolongs as the preference score increases. The EEG channels T3 is a forcible recording for detecting the time characteristic variation in brain.

Chapter III has extended the relationship between subjective preference and the effective duration of ACF in the α-wave range to examine subsequence reverberation time. Remarkably found that τ_e, ACF in the α-wave range may function as the scale values of subjective preference.

Chapter IV has successfully applied the findings in chapter II and III to simple time cognition, auditory tempo. The effective duration of ACF (τ_e) of CBW in the α-wave range is a efficient and consistent objective parameter to obseve the preference in surroundings.

Chapter V is another project to examine the visual tempo by using effective duration of ACF of CBW in the α-wave range. Besides the fact that the correlation was found to be consistent, the hemispheric specialization was also reconfirmed by analyzing the cross-correlation function. A signal propagation phenomenon on the horizontal cortex may idnetify the temporal coding between them.

Chapter VI reviewed the cerebral hemispheric specialization theory by cross-correlation analyses. The data employed in chapter II and III were used for calculations. The maximum values of the cross-correlation function between left and right EEG channels reveal a specialized management process for temporal information. It also supports the parallel system in the auditory pathway model proposed by Ando [1].

Chapter VII summarized the results from chapter II to VI, and tackled some interesting problems in present study. They give us the conclusion of the present study :1). Cerebral hemispheric dominance hypothses and the subjective judgement processes model in the auditory path (**Fig. 1.5**) have been confirmed by the effective duration of ACF (τ_e) and the maximum values of CCF in the α-wave range. 2). The value of τ_e in the α-wave range in a 2.5 s linear sum of ACF prolongs when the scale value of subjective preference increasing in case that physical factors changed in environments. 3). The value of τ_e, ACF in the α-wave range may function as the scale values of subjective preference pertaining to individual differences in changing physical factors.

7. 2 FURTHER PROBLEMS

Even though the findings of this study clearly support the autocorrelation processing in the brain, ideas to improve it for environmental preferences are needed in hurry. For example, Mouri and Ando[42] have examined EEG in the α-wave range using autocorrealtion analyses for evaluating the working gemutlich in an office. Especially, the results of this study always requests a universal appointment for the experiments. This kind of study requires longer observation and more general examination, since individual cases provide restricted variation. In case of changing T_{sub} in the Chapter III, individual difference gave us large trouble for universal identification (**APPENDIX C, Fig. A-4**). But individual difference provides us a high correlation for preference prediction by analyzing ACF of EEG in the α-wave range. There is a problem to summarize a fucntion with the same unit of preferred scales by τ_e of brain waves for arbitrarily physical factor's changing. Although the factors were independent in the experiments as we assumed, we also need to examine their compatibility for psychological scaling in the next apporach(**APPENDIX G**).

The autocorrelator for continuous brain waves (CBW) in the α-wave range is a method of average subject. It means that there are biases in system being always involved. Is more discussion of statistical processing in ACF analyses a benefit for noise elimination?

A segmentation method for the psychological momentary storage phenomenon is assumed to calculate a 2.5 s linear sum in ACF. It correlates well to the analyses of CBW in the α-wave range, but they were examined only for changing the initial delay of a single reflection (Δt_1) in a music sound field. Is it also suitable in visual research ?

The cross-correaltion analyses also considered whether utilizing aurally or visually evoked potential or not ? This is because an extreme short delay within 100 ms, was always detected.

REFERENCES

[1] Ando, Y., Concert Hall Acoustics, Springer-Verlag, Heidelberg (1985).

[2] Ando, Y., Okano, T., & Takezoe, Y., "The Running Autocorrelation Function of Different Music Signals Relating to Preferred temporal Parameters of Sound Fields," J. Acoust. Soc. Am., 86 (1989) 644-649.

[3] Ando,Y., & Imamura, M., "Subjective PreferenceTests for Sound Fields in Concert Halls Simulated by the Aid of a Computer," J. of Sound Vibration, 65 (1979) 229-239.

[4] Thurstone, L. L., "A Law of Comparative Judgment," Psychol. Rev., 34 (1927) 273-289.

[5] Burd, V. A. N., "Nachhallfreie Musik für Akustische Modelluntersuchungen," Rundfunktech. Mitteilungen, 13 (1969) 200-201.

[6] Ichikawa, G., et al, " The Logarithmical Presentation for Auditory Evoked Potential ," Audiology Jpn., 26 (1983) 735-739.

[7] Morrell, L. K., & Salamy, J. G., "Hemispheric Asymmetry of Electrocortical Responses to Speech Stimuli," Science, 174 (1971) 164-166.

[8] Ando. Y., "Evoked Potentials Relating to the Subjective Preference of Sound Fields," Acoustica, 76 (1992) 292-296.

[9] Sperry, R. W., "Lateral Preference in the Identification of Patterned Stimuli," J. Acoust. Soc. Am., 47 (1970) 574-578.

[10] Lindsley, D. B., "Psychological Phenomena and the Electroencephalogram," Electroenceph. Clin. Neurophysiol., 4 (1952) 443-456.

[11] Davidson, R. J., & Ehrlichman, H., "Lateralized Cognitive Processes and Electroencephalogram," Science, 207 (1980) 1005-1007.

[12] Praetorius, H. M., Bodenstein, G., & Creutzfeldt, O. D., "Adaptive Segmentation of EEG Records: A New Approach to Automatic EEG Analysis," Electro. & Clin. Neuro., 42 (1977) 84-94.

[13] Ando, Y., Kang, S. H., & Morita, K., "On the Relationship between Auditory-Evoked Potential and Subjective Preference for Sound Field," J. Acoust. Soc. Jpn. (E), 8 (1987) 197-204.

[14] Ando, Y., Kang, S. H., & Nagamatsu, H., "On the Auditory-Evoked Potential in Relation to the IACC of Sound Field," J. Acoust. Soc. Jpn. (E), 8 (1987) 183-190.

[15] Ando, Y., "Subjective Preference in Relation to Objective Parameters of Music Sound Field with a Single Echo," J. Acoust. Soc. Am. 62 (1977) 1436-1441.

[16] Fraisse, P., "Rhythm and Tempo" in the Psychology of music, edited by D. Deutsch (Academic, Orlandoi, FL, 1982), Chap.6, 149-180.

[17] Wallian, J. E. W. "Experimental Studies of Rhythm and Time", Psychological Review, 18 (1911) 100-131.

[18] Ando, Y. & Watanabe, T., "Evoked responses to sound enviroments" J. Acoust. Soc. Jpn.(in Japanese), 45 (1989) 794-799.

[19] Tohyama, M., Suzuki, H., & Ando, Y., The Nature and technology of Acoustic Space, Academic Press, London, (1995).

[20] Mosteller, F., "Remarks on Method of Paired Comparison: I. The Least Squares Solution Assuming Equal Standard Deviations and Equal Correlations," Psychometrika,16 (1951) 3-9.

[21] Ando, Y., Brain., P. J., & Bosworth., T., "Theory of Planning Physical Environments Incorporating Spatial and temporal Values," Mem. Grad. School Sci. & technol., Kobe Univ., 14-A (1996) 67-92.

[22] Ando, Y., Sato, S., Nakajima, T., & Sakurai, M., "Acoustic Design of a Concert Hall Applying the Theory of Subjective Preference, and the Acoustic Measurement after Construction," Acustica, (1997) inprint.

[23] Takatsu, A., Mori, Y., & Ando, Y., "The Architectural and Acoustic Design of a Circular Event Halls Using the Interview Method," Proceedings of MCHA95, Academic Press, London (1997).

[24] Ando, Y., Concert Hall Acoustics, Springer-Verlag, Tokyo, Japanese Edition with Appendix (1987).

[25] Drake, C., & Botte, M. C., "Tempo Sensitivity in Auditory Sequences: Evidence for a Multiple-look Model," Perception & Psychophysics, 54(3) (1993) 277-286.

[26] Fraisse, P., "Perception and Estimation of Time," Ann. Rev. Psychol., 35 (1984) 1-36.

[27] Mishima, J., "Fundamental Research on the Constancy of Mental tempo," Japanese J. of Psychol., 22 (1951-1952) 12-28.

[28] Mishima, J.,"On the Factors of the Mental Tempo," Jap. Psychol. Research, 4 (1956) 27-37.

[29] Kukimoto, N., & Takeda, T., "On Extract Method for the Suitable Tempo and Rhythm Pattern," Technical Report of IEICE (in Japanese), 45 (1996) 33-38.

[30] Hanna, T. E., "Discrimination of Reproducible Noise as a Function of Bandwith and Duration," Perception & Psychphysics, 36 (1984) 409-416.

[31] Ando, Y., and Chen, C. Y., "On the Analysis of Autocorrelation Function of a-waves on the Left and Right Cerebral Hemispheres in Relation to the Delay Time of Single Sound Reflection," J. Archi. Plann. Environ. Engng. AIJ., 488 (1996) 67-73.

[32] Chen, C. Y., and Ando, Y., "On the Relationship Between the Autocorrelation Function of the a-waves on the Left and Right Hemispheres and Subjective Preference for the Reverberation Time of Music Sound Field," J. Archi. Plann. Environ. Engng., AIJ., 489 (1996) 73-80.

[33] Chen, C. Y., Ryugo, H., and Ando, Y., "Relationship Between Subjective Preference and the Autocorrelation Function of Left and Right Cortical a-waves Responding to the Noise-Burst Tempo," J. Archi. Plann. Environ. Engng., AIJ., 497 (1997) 67-74.

[34] Nisho, K., and Ando, Y., "On the Relationship Between the Autocorrelation Function of Continuous Brain Waves and the Subjective Preference of the Sound Field in Change of the IACC," Program of 3rd Joint Meeting: J. Acoust. Soc. Am., 100 (1996) 2787.

[35] Hecht, S., and Verrijp, C. D., "Intermittent stimulation by light. IV. A theoretical interpretation of the quantitative data of flicker," J. of General Physio., 17 (1933) 251-265.

[36] Mowbray, G. H., and Gebhard, J. W., "Differential Sensitivity of Peripheral Retina to Intermittent Light," Science, 132 (1960) 672-674.

[37] Suzanne, P. M., and Douglas, G. T., "Discrimination of time: comparison of foveal and peripheral sensitivity," J. Opt. Soc. Am., Vol 1, No. 6 (1984) 620-627.

[38] Mo, S. S., and Michalski, V. A., "Judgement of Temporal Duration of Area as a Function of Stimulus Configuration," Psychonomic Science, 27 (1972) 97-98.

[39] Tyler, C. W., "Analysis of Visual Modulation Sensitivity. II. Peripheral retina and the role of photoreceptor dimensions," J. Opt. Soc. Am., A2 (1985) 393-398.

[40] Zacks, J. L., "Temporal Summation Phenomena at Threshold: Their relation to visual mechanisms," Science, 170 (1970) 197-199.

[41] Ando, Y., Yamamoto, K., Nagamatsu, H., & Kang, S. H., "Auditory Brainstem Response

(ABR) in Relation to the Horizontal Angle of Sound Incidence," Acoustics letters, 15 (1991) 57-64.

[42] Mouri, K., and Ando, Y., "On the Sound Environment for the Right and Left Human Hemispheric Tasks," Program of 3rd Joint Meeting: J. Acoust. Soc. Am., 100 (1996) 2787.

[43] Jasper, H. H., "The 10 - 20 Electrode System of the International Federation," Electroenceph. Clin. Neurophysiol, 10 (1958) 371-375.

APPENDIX

APPENDIX A

THE INTERNATIONAL 10/20 PLACEMENT SYSTEM

The standardized placement of 10/20 electrodes on the left and right hemispheres is employed throughout this study, which was appointed by Dr. Jasper [43] in second international congress in Paris in 1949. The determinded positions of 10/20 method have to be applied in anatomical studies (**Fig. A-1**) in the average subjects. An illustration is roughly indicated in **Fig. A-2**. Owing to whole studies in relation to the temporal information, a temporal aera for auditory cognition in both left and right hemispheres, T3 and T4, over Sylvian fissures were selected. And the T5,T6 are near to the primary visual field also applied in **Chapter V**, which indicated in **Fig. A-1.**

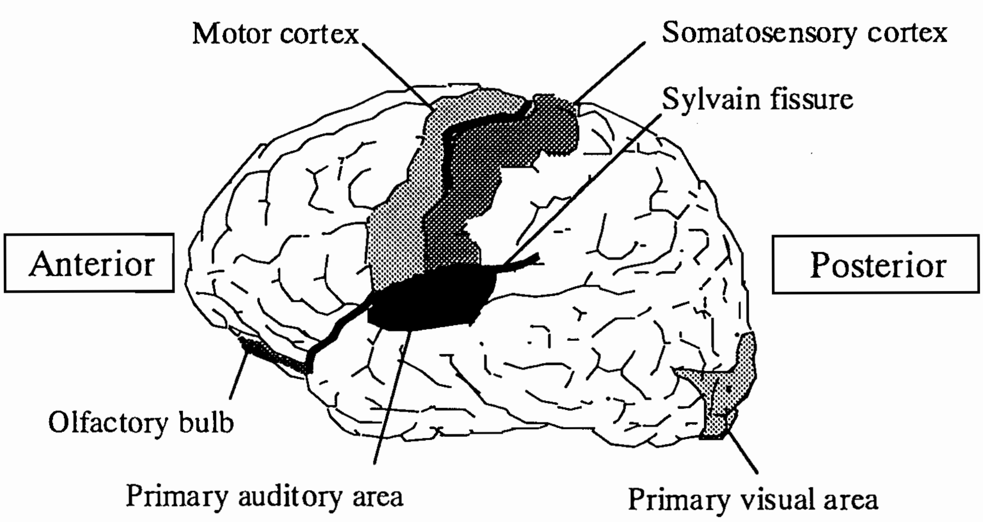


Fig. A-1. The electrodes of 10/20 placements are designed by considering the positions of anatomical studies.
Note: Reference: Evans, E. F. and Wilson, J. P., Psychphsics and Physiology of Hearing, 1974.

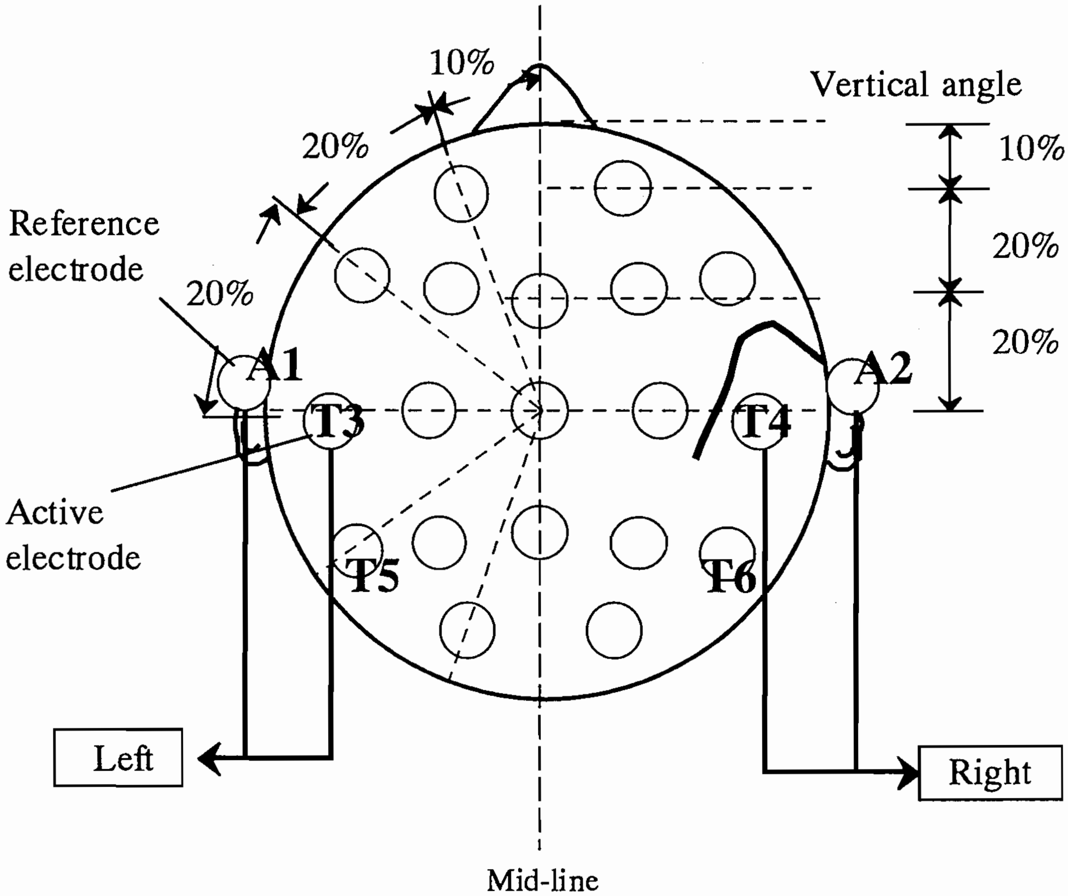
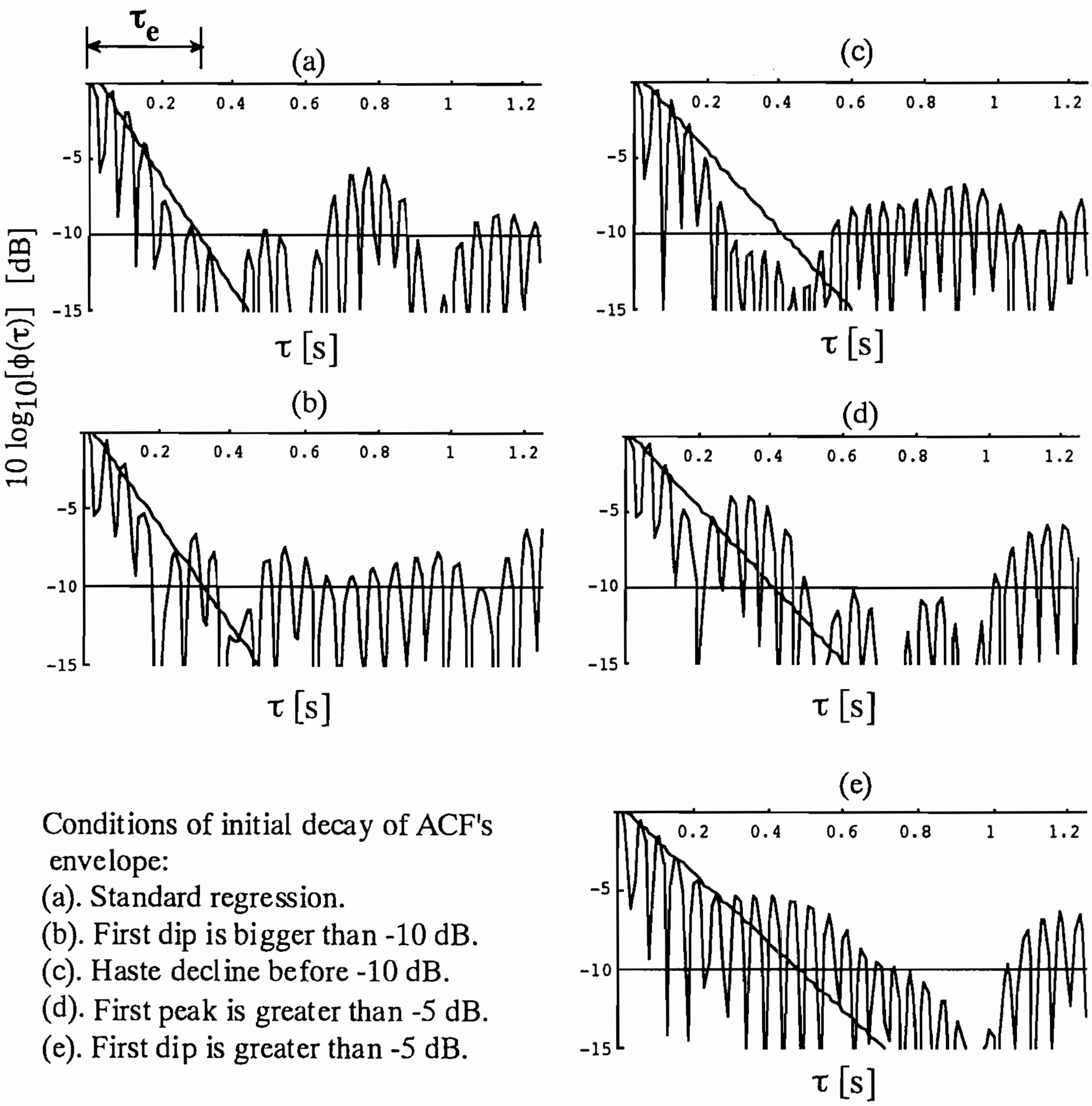


Fig. A-2. Based upon the vertex between the mid-line, each cerebral hemisphere is devided to 10 per cent and 20 horizontal angle (indecated by parallel dash-line) on cortex plane. Similarly, in the vertical angle from nasion to vertex or vertex to inion are also devided by 10, 20 per cent. These divisions denote the places of 10/20 electrodes.

APPENDIX B

There are some cases of normalized ACF in α-waves range of CBW, which provided us to define the effective duration (τ_e) by a linear regression satisfied either (0 dB > $\mathrm{Log}(\Phi_x(\tau))$ > - 5dB) or (0 ms < τ < 500ms) as interpretation. They are illustrated in **Fig. A-3.**



Conditions of initial decay of ACF's envelope:
(a). Standard regression.
(b). First dip is bigger than -10 dB.
(c). Haste decline before -10 dB.
(d). First peak is greater than -5 dB.
(e). First dip is greater than -5 dB.

Fig. A-3. A linear sum in α-waves range of CBWs has an initial decline of envelope of ACF. The effective duration of ACF (τ_e) is defined as it cross to -10 dB at that of delay. But there were some exception can not fair to fit a straight line regression in a range of 0 to -10 dB of the power of the normalized ACF. The regressive range was changed to fit in the range of either $0 < 10 \log_{10}[\phi(\tau)] < -5$ dB or $0 < \tau < 0.5$ s for all.

APPENDIX C

The individual tendency of τ_e, ACF in α-waves range were indicated clearly, which corresponded to the varied T_{sub} from 0.2 to 1.2 s and 1.2 to 6.4 s. A consistency for 10 subjects was obtained by 0.2 to 1.2 s pair in the left hemisphere only. It demostrates that the value of τ_e, ACF in α-waves range is an efficient method for evaluating subjective preference in case of changing temporal factors in music fields, but individual difference are large in values.

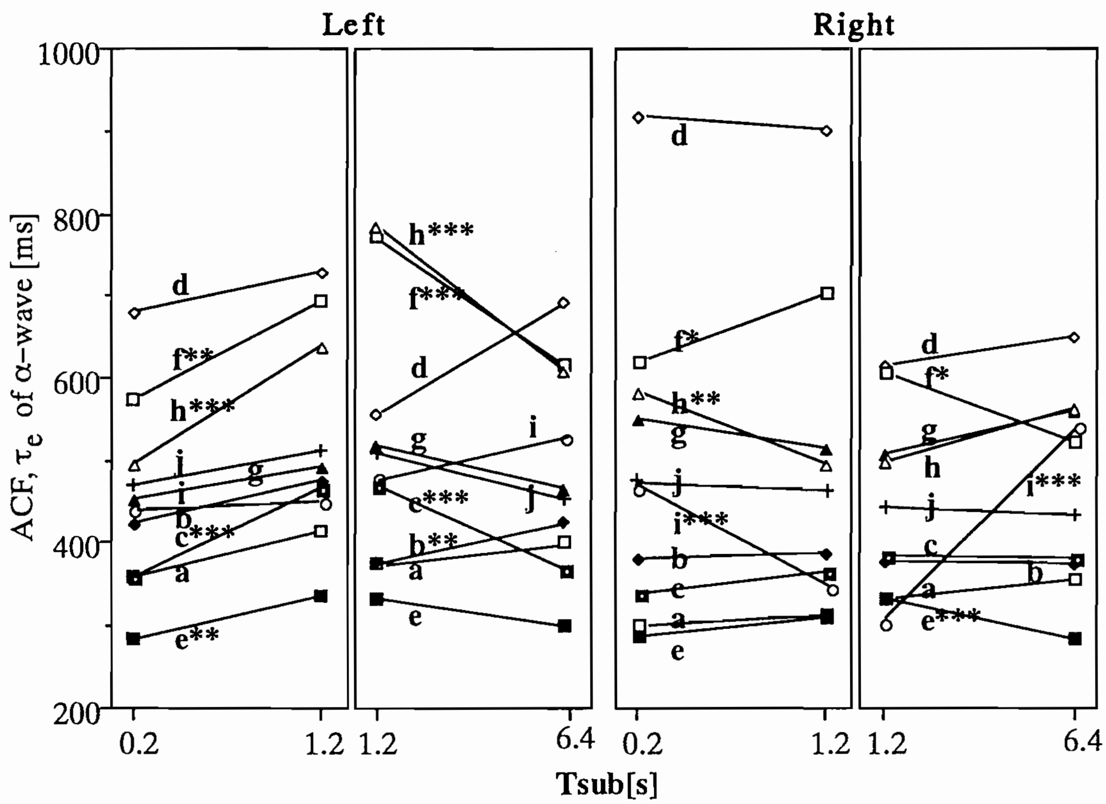


Fig. A-4. Average values of τ_e in α-waves range were observed in left hemisphere and right of 10 subjects (a~j) that responded to two kinds of stimulus pairs (0.2 & 1.2 s and 1.2 & 6.4 s).
(NOTE: " * " denotes significant levels of individual results with respect to effect of T_{sub} by one-way ANOVA. And * $p<0.1$, ** $p<0.05$, *** $p<0.01$)

APPENDIX D

In the discussion of relationship between scale values (SV) of subjective preference and τ_e, ACF in α-waves range, corrected SV by coefficient of consistency in individual judgements will enhence the correlation between them. The method is to eliminate the answers that was examined by circular triad test has a lower agreement below 0.5 of consistency. As listed in **Table A-1,** the responses for the varied periods of noise burst. It provided us to promote the coefficient of correlation r, between the ratios of τ_e, ACF in α-waves range and the difference of SVs for (550 &1000) ms pair from 0.74 to 0.80.

The coefficient of consistency was obtained by

$$\zeta = 1 - \frac{24d}{k^3 - 4k} \text{ or } 1 - \frac{24d}{k^3 - k}, \text{ if k is an even.} \qquad \text{(A-1)}$$

where k is the levels of compared samples, d is calculated by

$$d = \frac{1}{6}\{k(k-1)(k-2) - 3\sum_{i=1}^{k} a_i(a_i - 1)\}$$

where a_i is the sum of times that judged favor to the other levels.

Table A-1. The results of the coefficient of consistency for paired-comparison method provide us to reject the worse data in every 8 series of each subject.

Subjects	A	B	C	D	E	F	G	H	I	J
	0.500	0.500	0.625	0.875	1.000	1.000	0.500	~~0.375~~	0.625	0.625
	1.000	~~0.375~~	0.875	0.750	1.000	1.000	0.875	0.625	0.750	1.000
	1.000	0.625	0.500	0.625	1.000	1.000	0.500	0.500	0.750	0.750
	1.000	0.750	1.000	1.000	0.875	1.000	~~0.250~~	0.625	0.625	0.500
	0.500	~~0.000~~	0.875	1.000	0.750	1.000	~~0.250~~	0.625	0.750	1.000
	0.750	1.000	0.500	1.000	1.000	0.875	~~0.000~~	1.000	0.875	0.875
	0.750	~~0.250~~	0.750	1.000	1.000	0.625	~~0.125~~	0.500	1.000	1.000
	1.000	0.625	0.750	0.875	~~0.125~~	~~0.250~~	0.500	0.875	0.750	~~0.000~~

APPENDIX E

THE VALUES OF τ_e, ACF IN α-WAVES RANGE FOR EACH STUDY

Table A-2. The average values of τ_e (ms), ACF in α-waves range in changing Δt_1 for 11subjects.

	A	B	C	D	E	F	G	H	I	J	K
35 L	325	282	259	532	513	723	575	598	903	754	371
245L	274	267	224	496	475	655	524	513	797	665	291
35 R	374	258	247	505	604	659	584	702	566	693	393
245R	360	300	266	498	575	613	646	666	595	741	409

Note: for example, 35L: τ_e referred to Δt_1 = 35 ms in left hemispheres (T3 channels).

Table A-3. The average values of τ_e (ms), ACF in α-waves range in changing T_{sub} for 10 subjects.

	a	b	c	d	e	f	g	h	i	j
(0.2 & 1.2) s pair										
0.2R	293	376	335	466	281	582	544	576	462	465
1.2R	309	381	349	505	303	621	509	490	346	457
0.2L	351	414	351	398	275	463	445	487	434	459
1.2L	406	468	431	479	328	583	482	628	441	501
(1.2 & 6.4) s pair										
1.2R	326	372	380	460	327	569	501	494	305	438
6.4R	351	370	376	456	280	503	554	559	532	427
1.2L	370	370	433	409	328	628	513	778	473	502
6.4L	394	421	361	468	295	528	460	604	524	447

Note: for example, 0.2L: τ_e referred to T_{sub} = 0.2 s in left hemispheres (T3 channels).

Table A-4. The average values of τ_e (ms), ACF in α-waves range in changing periods of subjective tempo for 10 subjects.

	A	B	C	D	E	F	G	H	I	J
(550 & 300) ms pair										
550 R	433	543	412	509	422	362	513	314	550	331
300 R	486	421	478	506	407	344	453	315	582	330
550 L	505	480	457	521	532	403	467	373	561	373
1000L	400	422	402	459	377	328	375	295	588	306
(550 & 1000) ms pair										
550 R	470	469	481	445	356	375	515	357	536	332
1000R	383	461	557	422	416	309	514	370	551	341
550 L	505	480	457	521	532	403	467	373	561	373
1000L	400	422	402	459	377	328	375	295	588	306

Note: for example, 550L: τ_e referred to period = 550 ms in left hemispheres (T3 channels).

Table A-5. The average values of τ_e (ms), ACF in α-waves range in changing periods of visual tempo for 7 subjects.

		A	B	C	D	E	F	G
	Target size = 1°							
(0.2 & 0.6) s pair	0.2LT3	315	357	265	347	322	311	348
	0.2LT5	295	313	296	343	292	298	324
	0.6LT3	348	344	346	345	387	356	374
	0.6LT5	360	419	395	344	331	329	366
	0.2RT4	350	360	333	336	344	309	363
	0.2RT6	334	325	326	353	329	363	316
	0.6RT4	318	381	325	312	369	323	377
	0.6RT6	398	355	353	365	344	377	337
(3.2 & 0.6) s pair	3.2LT3	310	329	366	320	354	318	352
	3.2LT5	313	372	339	313	293	322	344
	0.6LT3	384	384	291	352	330	374	344
	0.6LT5	376	331	344	369	340	383	364
	3.2RT4	343	343	392	410	364	350	341
	3.2RT6	312	339	371	365	348	360	412
	0.6RT4	309	309	315	345	328	346	329
	0.6RT6	317	349	328	343	353	331	357
	Target size = 5°							
(0.2 & 0.8) s pair	0.2LT3	336	340	206	309	314	281	323
	0.2LT5	314	369	361	299	327	340	310
	0.8LT3	361	383	210	347	388	342	342
	0.8LT5	338	348	330	328	352	348	343
	0.2RT4	320	321	383	344	342	320	335
	0.2RT6	341	348	360	366	347	325	377
	0.8RT4	335	331	329	338	325	367	366
	0.8RT6	314	376	327	373	365	328	355
(3.2 & 0.8) s pair	3.2LT3	325	326	364	315	303	309	301
	3.2LT5	320	355	332	284	303	294	319
	0.8LT3	322	340	319	332	339	378	340
	0.8LT5	389	347	295	356	356	335	389
	3.2RT4	365	363	356	311	341	320	317
	3.2RT6	359	353	302	336	329	359	306
	0.8RT4	308	362	325	352	365	334	338
	0.8RT6	331	350	326	330	359	372	331

Note: for example, 0.2LT3: τ_e referred to period = 0.2 s in left hemispheres (T3 channels).

APPENDIX F

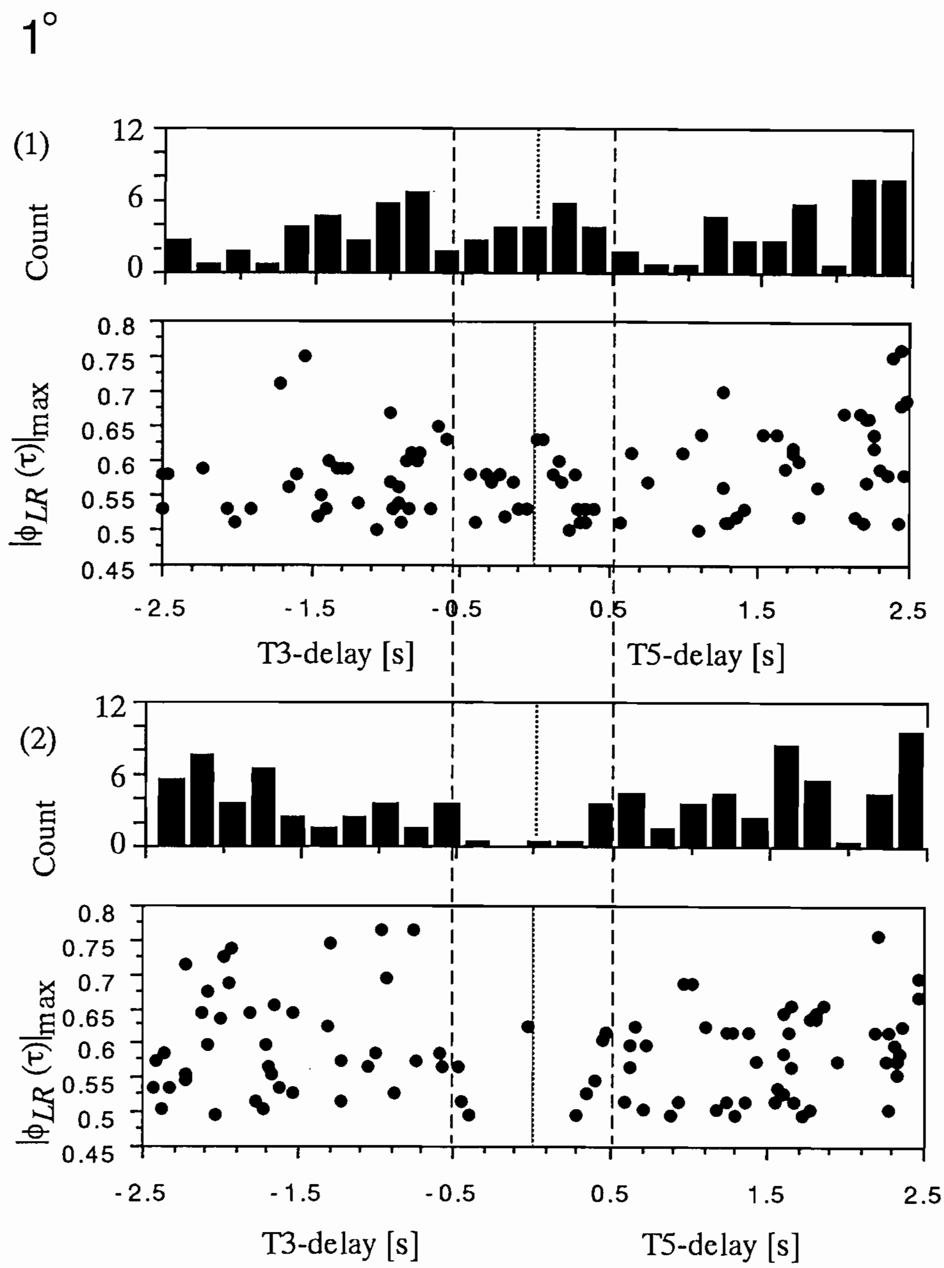


Fig. A-5a. The values of $|\phi_{LR}(\tau)|_{max}$ in between T3 and T5 channels were indecated in frequency distribution, and the scatter diagram showed below as references. They are the responses of changed period from 0.2 s (1) to 3.2 s (2), both of them were presented referring to period = 0.8 s in a target of 1°. In the range of -0.5 to 0.5 s delay shows significant different between periods, 0.2 and 3.2 s, where at 3.2 s, a gathering at T5 channel is approximately 1.6 s delay , but this delay prolonged in T3 channel.

5 °

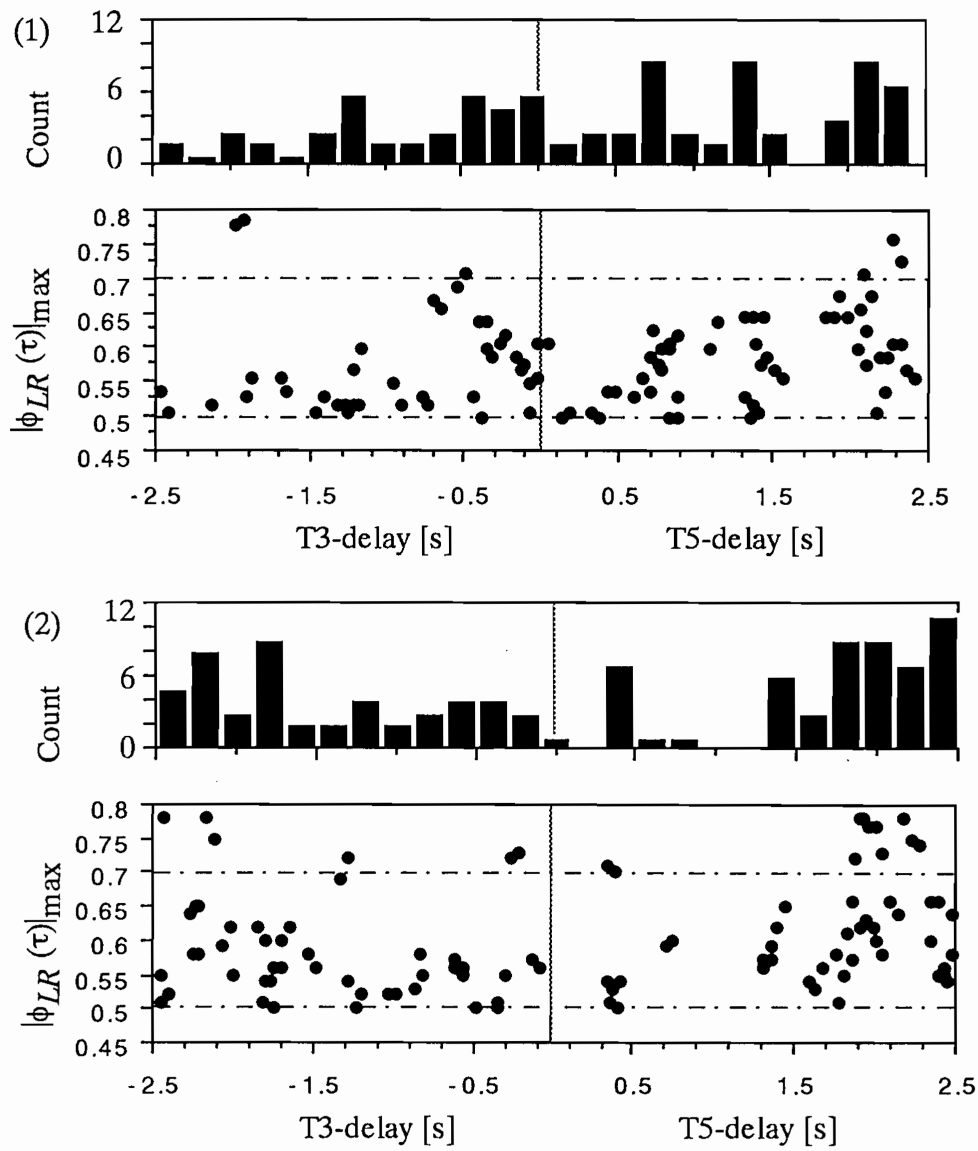


Fig. A-5b. The values of $|\phi_{LR}(\tau)|_{max}$ in between T3 and T5 channels were indecated in frequency distribution, and the scatter diagram showed below as references. They are the responses of changed period = 0.2 s (1) to 3.2 s (2), both of them were presented referring to period = 0.8 s in a target of 5 °.

APPENDEX G

The individual difference may provide us a function for preference prediction by analyzing ACF of EEG in the α-wave range. There is a problem that high correlation in each case are difficult to summarize the same unit of preferred scales by τ_e of brain waves for arbitrarily physical factor's changing.

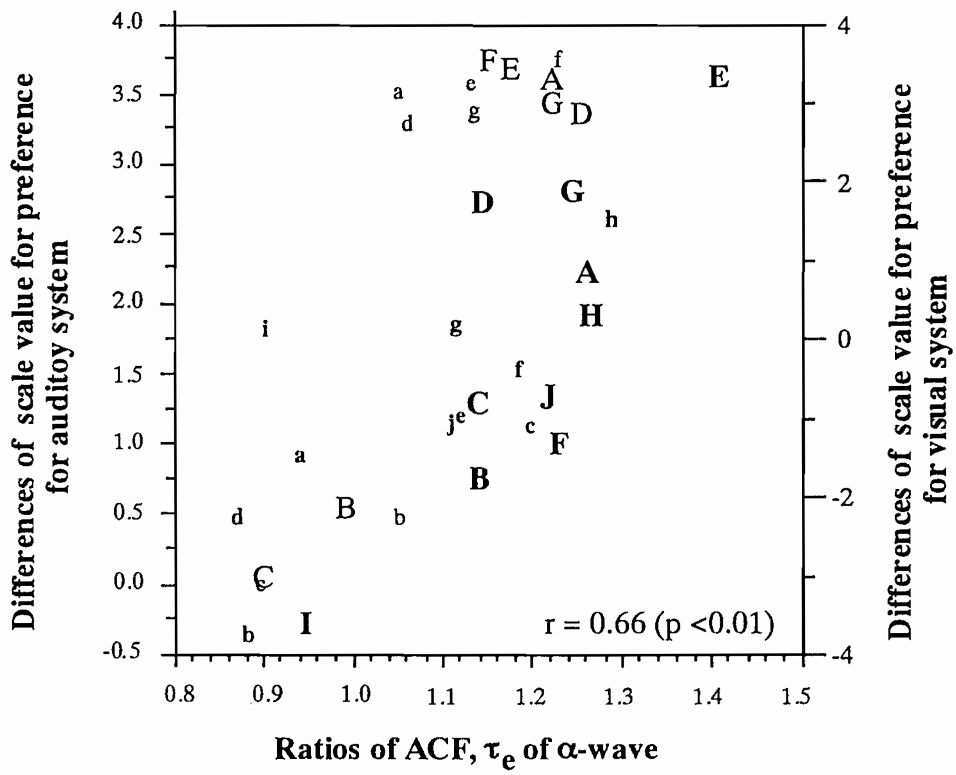


Fig. A-6 Relationship between differences of the scale values of preference (SV) and ratios of τ_e of α-waves in the left hemisphere for each subject.

Note: A ~ J : periods (T3), a ~ j : T_{sub} (T3), A ~ G: visual tenpo (T5), a ~ g : visual tempo (T3).

LIST OF PUBLICATIONS

The brackets at the end of reference indicate chapter's number where paper are cited in this dissertation.

Full Papers :

1. On the analysis of autocorrelation function of α-waves on the left and right cerebral hemispheres in relation to the delay time of single sound reflection. - Published in J. Archi. Plann. Environ. Engng. AIJ., 488 (1996) 67-73. **(Chapter II).**
2. On the relationship between the autocorrelation function of the α-waves on the left and right hemispheres and subjective preference for the reverberation time of music sound field. - Published in J. Archi. Plann. Environ. Engng., AIJ., 489 (1996) 73-80. **(Chapter III).**
3. Relationship between subjective preference and the autocorrelation function of left and right cortical α-waves responding to the noise-burst tempo. - J. Archi. Plann. Environ. Engng., AIJ., 497 (1997) 67-74 **(Chapter IV).**
4. Relationship between subjective preference and the autocorrelation function of left and right cortical α-waves responding to the visual tempo. - J. Archi. Plann. Environ. Engng., Architecture Institute Japan, in preparation **(Chapter V).**
5. Dynamic analysis of cross-correlation function of left and right hemispheric α-waves in relation to interaction between EEG channels. - J. Archi. Plann. Environ. Engng., Architecture Institute Japan, in preparation **(Chapter VI).**

Contributed paper :

1. On the left and right cerebral hemispheres in relation to the delay time of a single reflection for music sound field. - Reports of Meetings of Architectural Society of Japan in Osaka, July 1992, pp. 33-36. **(Chapter II).**
2. On the left and right cerebral hemispheres in relation to the delay time of a single reflection for music sound field. - Reports of Meetings of Architectural Society of Japan in Nigata, August 1992, pp. 427-428. **(Chapter II).**
3. An analysis of continuous EEG in relation to the physical factor of sound field. - Reports

of Meetings of Architectural Society of Japan in Osaka, July 1994, pp. 21-24. **(Chapter II).**

4. An analysis of continuous EEG in relation to the physical factor of sound field. - Reports of Meetings of Architectural Society of Japan in Hokaito, July 1994, pp. 1993-1994. **(Chapter II).**

5. Relationship between subjective preference and the autocorrelation function of left and right cortical α-waves responding to the visual tempo. - Reports of Meetings of Architectural Society of Japan in Osaka, July 1997, sumitted. **(ChapterV).**