Analysis of EEG Relating to Subjective Preference for Horizontal Visual Motion

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This study aimed to identify the relationship between human brain response and subjective preference for horizontal visual motion of a sinusoidal movement over varying periods. Electroencephalograms (EEGs) were recorded during the presentation of the most or less preferred moving stimuli. Brain waves were analyzed using both the autocorrelation function (ACF) and cross-correlation function (CCF). The effective duration (τ_e) was analyzed from the initial range of the delay of ACF of the brain waves. The results showed that the value of τ_e of alpha waves for stimulus in the most preferred condition was longer than that for stimulus in the less preferred conditions. In addition, the maximum value of the CCF ($|\phi(\tau)|_{max}$) between brain waves recorded at different electrode sites was analyzed. The results showed that the value of $|\phi(\tau)|_{max}$ of alpha waves for stimulus in the most preferred was greater than that for the stimulus in the less preferred conditions. These results indicate that the brain repeats the rhythm in the alpha range in the time domain, and that this activity spreads wider over the human brain cortex as a result of the presentation of stimuli with preferred rather than with less preferred motion.

Keywords: visual motion perception, electroencephalography (EEG), subjective preference,alpha wave, autocorrelation function (ACF), cross-correlation function (CCF)

1.INTRODUCTION

Human visual perception has been investigated extensively in both psychological and physiological studies. However the relationship between human psychological responses such as subjective preference and physiological response to visual stimulus is still unclear. In a complete description of the human perceptual evaluation of the environment, both subjective and objective evaluations need to be considered. Therefore, this study focuses on the relationship between the objective, by measuring the human brain response, and the subjective induced by varying stimulus parameters of visual environments.

It is reported that electroencephalograms (EEGs) correspond well to alpha waves, which are always produced in relaxed states and are associated with free creative thought, and so are useful in discussions of human brain activity in relation to human behavioral states [1]. In auditory environments, a method of using ACF was developed to analyze brain waves in the alpha range, and the effective duration of the envelope of the normalized ACF (τ_e) of the alpha waves was analyzed when the initial time-delay gap between the direct sound and the first reflection (Δt_1) and the subsequent reverberation time (T_{sub}), which are temporal factors of a sound field, was varied [2, 3]. The studies found that the value of τ_e of the ACF of the alpha waves was longer in preferred conditions caused by these temporal factors. The results revealed a possible correlation between brain activity and subjective preference [4]. We have applied this subjective preference theory, which was developed for auditory environments, to visual environments. We hypothesized that subjective preference for visual stimuli is reflected in physiological responses, such as human brain activity.

In visual environments, the relationship between human brain activity and subjective preference for the period of a flickering light was investigated [5, 6]. The results showed that the value of τ_e of the ACF of the EEG alpha waves was longer, and that the maximum value of the cross-correlation function (CCF) of the EEG alpha waves ($|\phi(\tau)|_{max}$) was greater during the presentation of the stimulus in the preferred than

a)Now at Life Electronics Laboratory, National Institute of Advanced Industrial Science and Technology (AIST), Midorigaoka, Ikeda, Osaka, 563-8577 Japan that in the less preferred condition. The knowledge obtained from the results of this study will be applicable to the design of lighting systems.

A foundation for a theory of planning physical environments has been suggested [1]. Factors to be considered for planning visual environments are proposed in the theory, for instance, as a temporal factor, the movement of the surface reflecting the light. Motion perception is one of the most important functions in visual systems for recognizing particular things within our environment. If the relationship between the temporal properties of the movement of an object and human brain activity can be identified, a method can be developed with direct application in the field of design of dynamic visual environments.

The aim of this study is to identify the relationship between human brain response and subjective preference as a primitive psychological response to horizontal visual motion varying the periods of the movement; that is, a temporal factor. In the present study, a single circular target moving sinusoidally in the horizontal direction was presented to the subjects. EEGs were recorded during the presentation of the stimuli in the most and less preferred conditions. Then, the τ_e of the brain waves and $|\phi(\tau)|_{max}$ between the brain waves measured at different electrodes were analyzed to determine the relationship between subjective preference and both τ_e and $|\phi(\tau)|_{max}$.

2. METHODS

2.1. Stimuli

Our stimuli consisted of white disks with a visual angle of 1.0° in diameter against a black background, as shown in Fig. 1. The stimuli were presented on a cathode ray tube (CRT) display placed in front of the subject at a viewing distance of 1.0 m in a dark chamber, and subjects' EEGs were recorded.

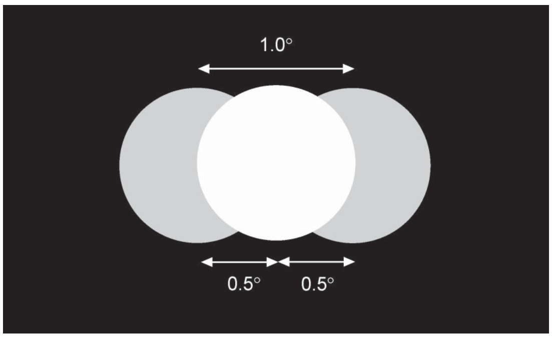

Fig. 1. A single circular target with sinusoidal movement was used for the visual stimuli moving in the horizontal direction.

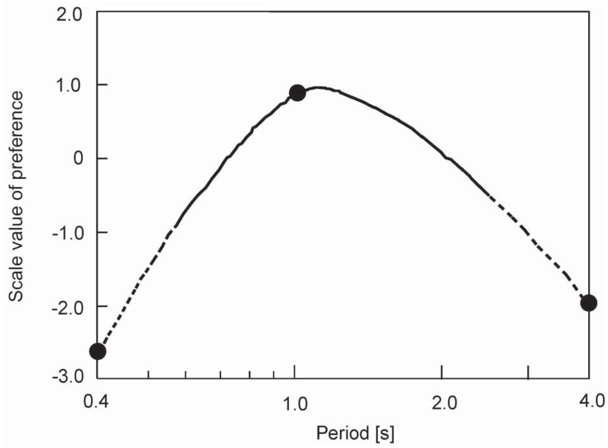

Fig. 2. Averaged scale values of subjective preference as a function of the period of the movement of the visual stimulus for ten subjects. The thick line shows the preference evaluation curve obtained from the results of our previous study [8]. The filled circle shows the period chosen in this study to enhance the difference of the scale values of subjective preference and the broken line shows the extended preference evaluation curve. The period indicates the duration for one complete rotation; that is, the moving stimulus with the period of 0.4 s was the fastest and that with the period of 4.0 s was the slowest in this experiment.

The amplitude was fixed at a visual angle of 0.5°. The movement of the stimulus is given by

$$h(t) = A\cos(2\pi \frac{t}{T}) \qquad (1)$$

where A is the amplitude and T is the period of the stimulus.

Subjective preference is a primitive human psychological response to an environment [1,7]. Our previous study investigated human subjective preference for a single circular target with sinusoidal movements moving horizontally [8]; the stimuli used in that study were identical to those in the present, and preference judgments were not very different between subjects. While the most preferred period of the stimuli $[T]_p$ was found at approximately 1.0 s, the subjective preference ratings decreased for shorter and longer periods, as depicted in Fig 2.

In the present study, stimuli with the most and less preferred periods were selected as paired stimuli to clarify the effect of subjective preference on EEG. Based on the results of our previous subjective preference test [8], 1.0 s was selected as the most preferred period of a stimulus; thus, this became the most preferred condition. We chose 0.4 s and 4.0 s as the less preferred periods; these then became the less preferred

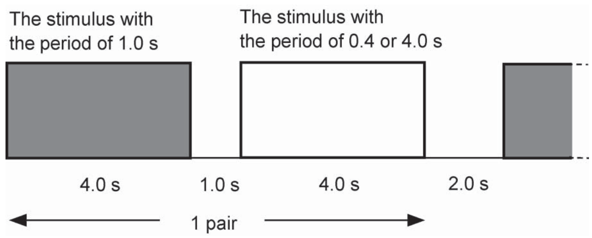

Fig. 3. Procedures for the presentation of the stimuli during EEG recoding. The period of the most preferred stimulus is 1.0 s. The period of the less preferred stimulus is 0.4 s in the experiment with pair 1, and 4.0 s in the experiment with pair 2.

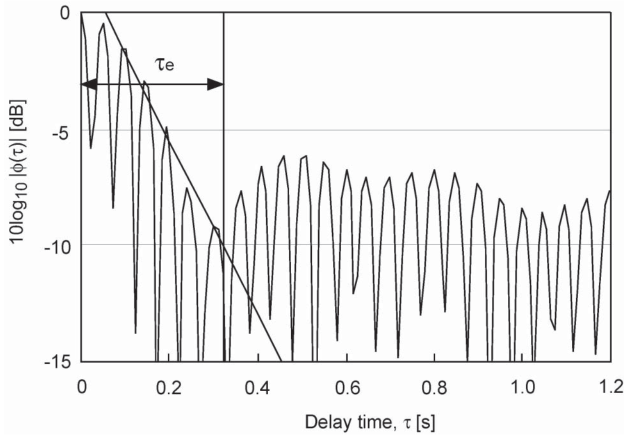

Fig. 4. Definition of the effective duration of ACF (τ_e).

conditions. Two pairs of stimuli were presented to determine either the scale value of subjective preference or if the period (velocity) of movement of the stimulus had an influence on the EEG. The pairs were determined: pair 1 [period T = 1.0 and 0.4 s] and pair 2 [period T = 1.0 and 4.0 s] as shown in Fig. 2. For each of these two stimulus pairs a separate experiment was conducted. The subjects were asked to watch the stimuli with the period of 1.0 s and a period of 0.4 or 4.0 s alternatively. As shown in Fig. 3, a pair of stimuli with 4.0 s duration was presented with an interval of 1.0 s, and each pair was presented successively ten times in one series with a 2.0 s repeated interval, and three series were conducted for all subjects.

Eight healthy young adults (aged 22-26 years) volunteered as subjects for this study. All had normal or corrected-to-normal vision.

2.2. EEG recording

During the EEG recordings, each subject was instructed to look straight ahead. The EEGs were recorded using six silver electrodes located at T3, T4, T5, T6, O1, and O2 according to the International 10-20 system [9]. The reference electrode was placed at Fz (midline electrode 30 % of distance from nasion to inion). The ground electrode was placed on the forehead. The EEGs were sampled at 100 Hz after passing through a 30-Hz low-pass filter and stored on digital tape for off-line processing. The recorded data were filtered with a digital-bandpass filter in following frequency bands: 4-8 (theta), 8-13 (alpha), 13-30 (beta).

2.3. Analysis procedures

2.3.1. Autocorrelation function (ACF)

It is known that, mathematically, the ACF and power density spectrum contain the same information. Four physical factors are obtained from the ACF [1]: (1) energy represented at zero delay, $\Phi(0)$; (2) effective duration of the envelope of the normalized ACF, τ_e, representing a type of repetitive feature containing the signal itself; and (3 and 4) the amplitude and the delay time of the first dominant peak of the normalized ACF, denoted, respectively, as τ_1 and ϕ_1.

The normalized ACF is defined by

$$\phi(\tau) = \frac{\Phi(\tau)}{\Phi(0)} \qquad (2)$$

where

$$\Phi(\tau) = \frac{1}{2T}\int_{-T}^{+T} \alpha(t)\alpha(t+\tau)dt. \qquad (3)$$

where 2T is the integration interval, τ is the time delay, and $\alpha(t)$ is the alpha wave in the EEG. Fig. 4 shows the logarithm of the absolute value of the ACF plotted as a function of the delay time. In most cases, the envelope decay of the initial part of the ACF can be fitted to a straight line ranging from 0 to –5 dB, and the effective duration τ_e of the ACF can be easily obtained from the decay rate extrapolated at –10 dB [3]. The integration interval (2T) was set at 2.5 s for the ACF analysis, which is the shortest duration needed for the subjects to make subjective preference judgments [3].

2.3.2. Cross-correlation function (CCF)

Let two signals be $\alpha_1(t)$ and $\alpha_2(t)$. The CCF for delay time τ is then defined by

$$\Phi_{12}(\tau) = \frac{1}{2T}\int_{-T}^{+T} \alpha_1(t)\alpha_2(t+\tau)dt. \qquad (4)$$

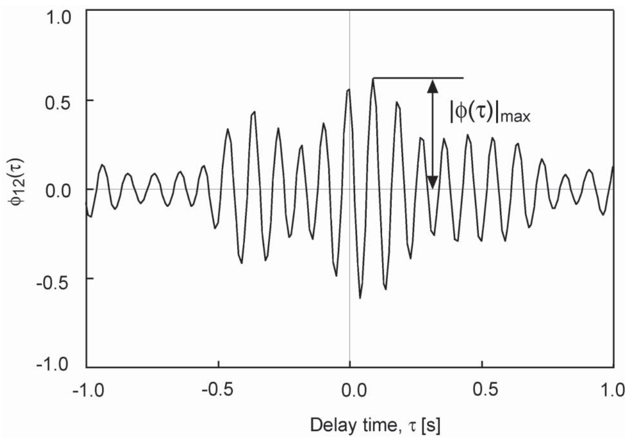

Fig. 5. Definition of $|\phi(\tau)|_{max}$ of a normalized CCF between the alpha waves measured at O1 and those measured at the other electrode sites.

The normalized CCF is given by

$$\phi_{12}(\tau) = \frac{\Phi_{12}(\tau)}{\sqrt{\Phi_{11}(0)\Phi_{22}(0)}}, \quad (5)$$

where $\Phi_{11}(0)$ and $\Phi_{22}(0)$ are ACFs at $\tau = 0$ of $\alpha_1(t)$ and $\alpha_2(t)$, respectively.

The integration interval was set at 2.5 s in the CCF analysis, as in the ACF analysis. An example of a normalized CCF is shown in Fig. 5. The value of $|\phi(\tau)|_{max}$ is defined as the maximum CCF value.

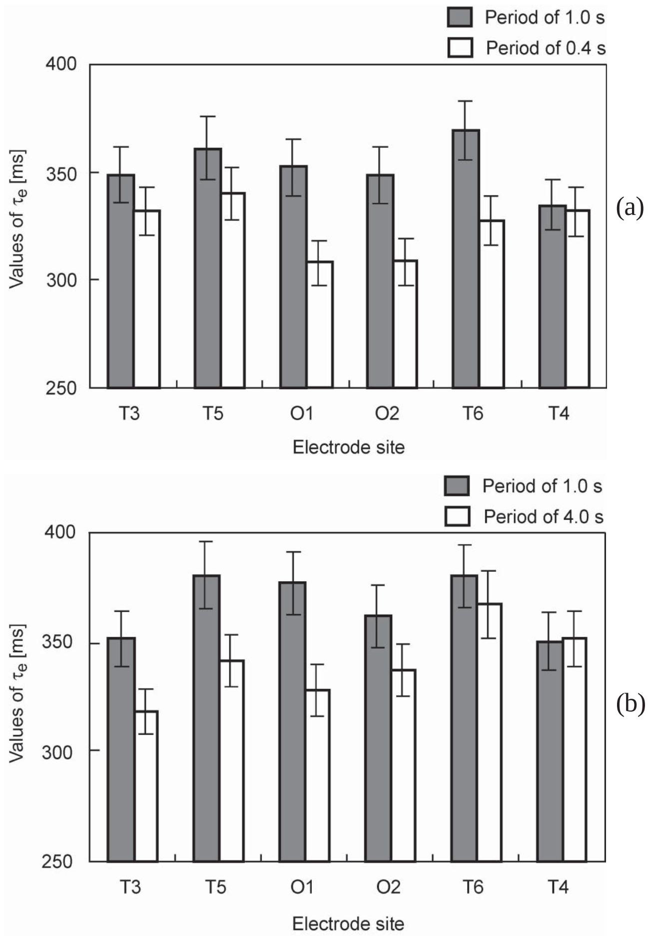

Fig. 6. Averaged values of τ_e of the ACF in the alpha range that responded to the change of the period under presentation of (a) pair 1 [T = 1.0 and 0.4 s], and (b) pair 2 [T = 1.0 and 4.0 s]. Error bars indicate SEM.

3. RESULTS

3.1. Results of ACF analysis

In ACF analyses, we focused on τ_e because this is a significant factor, as reported in previous studies [3, 4, 5]. The effects of the stimulus condition and electrode site on the value of τ_e were assessed by two-way analysis of variance (ANOVA) in

Table 1. Results of two-way ANOVA for the values of τ_e of ACF

Frequency band [Hz]	Factor	F-ratio	P-value	F-ratio	P-value
		Pair 1		Pair 2	
		Period of 1.0 and 0.4 s		Period of 1.0 and 4.0 s	
4 to 8	Stimulus condition	0.03	0.87	0.02	0.90
	Electrode site	0.19	0.97	0.96	0.44
	Stimulus condition and electrode site	0.32	0.90	0.24	0.95
8 to 13	Stimulus condition	14.77	<0.001	11.72	<0.001
	Electrode site	1.14	0.34	1.85	0.10
	Stimulus condition and electrode site	0.87	0.50	0.96	0.44
13 to 30	Stimulus condition	0.35	0.55	<0.001	0.99
	Electrode site	4.00	0.001	5.30	<0.001
	Stimulus condition and electrode site	0.90	0.48	0.42	0.84

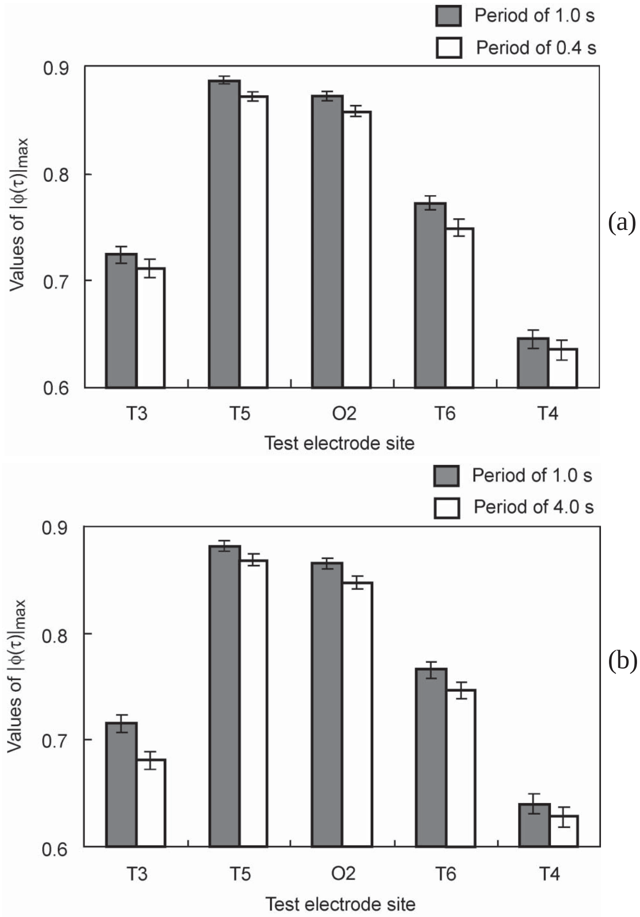

Fig. 7. Averaged values of $|\phi(\tau)|_{max}$ of the CCF in the alpha range that responded to the change of the period at comparison electrode O1 under presentation of (a) pair 1 [T = 1.0 and 0.4 s] and (b) pair 2 [T = 1.0 and 4.0 s]. Error bars indicate SEM.

each frequency range. The results of the analysis are summarized in Table 1. A significant effect of the stimulus condition was found in the alpha range when both pair 1 (period of 1.0 s as the most preferred condition and 0.4 s as the less preferred condition) and pair 2 (period of 1.0 s as the most preferred condition and 4.0 s as the less preferred condition) were presented. There was no significant effect from the stimulus conditions in the theta and beta ranges. Figs. 6a and b show the averaged values of τ_e in the alpha range for the eight subjects. The results showed that the stimulus with the period of 1.0 s induced a longer value of τ_e than those with periods of 0.4 or 4.0 s.

3.2. Results of CCF analysis

In CCF analyses, the values of $|\phi(\tau)|_{max}$ were analyzed to estimate the degree of correlation between cortical responses. We calculated the normalized CCF between the brain waves measured at electrode site O1 (comparison electrode) and those measured at the other electrode sites (test electrodes) because the differences between the values of τ_e for the two conditions were the greatest at O1 in the ACF analysis as shown in Fig. 6a and b. The effects of the stimulus condition and electrode site on the $|\phi(\tau)|_{max}$ values were assessed by two-way ANOVA in each frequency range. The results of the analysis are summarized in Table 2. Significant effects of the stimulus condition and electrode site were found in the alpha range when both pairs were presented. There was no significant effect from the stimulus conditions in the theta and beta ranges. As shown in Fig 7a and b the results revealed that the stimulus with the period of 1.0 s had a greater value of $|\phi(\tau)|_{max}$ in the alpha range than those with periods of 0.4 or 4.0 s. As Figs. 7a and b show, the values of $|\phi(\tau)|_{max}$ are greater in the posterior temporal and the occipital areas (T5, O2, respectively) than at the other sites for both pairs 1 and 2.

Table 2. Results of two-way ANOVA for the values of $|\phi(\tau)|_{max}$ of CCF

Frequency band [Hz]	Factor	F-ratio	P-value	F-ratio	P-value
		Pair 1		Pair 2	
		Period of 1.0 and 0.4 s		Period of 1.0 and 4.0 s	
4 to 8	Stimulus condition	0.15	0.70	0.002	0.96
	Electrode site	223.07	<0.001	217.34	<0.001
	Stimulus condition and electrode site	0.05	0.99	0.24	0.92
8 to 13	Stimulus condition	11.06	<0.001	17.73	<0.001
	Electrode site	409..40	<0.001	398.03	<0.001
	Stimulus condition and electrode site	0.23	0.92	0.73	0.57
13 to 30	Stimulus condition	0.09	0.76	0.81	0.37
	Electrode site	402.07	<0.001	428.59	<0.001
	Stimulus condition and electrode site	0.21	0.93	0.08	0.99

4. DISCUSSION

4.1. Values of τ_e in the alpha range

A significant effect of the stimulus condition on the value of τ_e was observed in the alpha range, but not in the theta or beta ranges. Therefore we concentrated on the values of τ_e in the alpha range, where the averaged τ_e values obtained for the stimuli with a period of 1.0 s were significantly longer than those for the stimuli with periods of 0.4 or 4.0 s, as shown in Fig. 6, although the differences between the scale values of the stimuli with the period of 1.0 s and the stimuli with periods of 0.4 or 4.0 s were not the same for all of the subjects because the stimuli were selected on averaged scale values of preference obtained form the results of previous subjective preference tests [8]. This result indicates that the values of τ_e in the alpha range were affected by subjective preference and not the period (velocity) of the stimulus. The value of τ_e of the ACF in the alpha range, which indicates the degree of persistence of the EEG alpha wave, is prolonged with a certain degree of coherence in the preferred condition. This may be because the brain repeats the rhythm in the alpha range, which reflects temporal behavior in the cortical area. This tendency of the τ_e values in the alpha range to increase in the preferred condition has been found in previous studies on the effects of varying the delay time of a single sound reflection [3], the reverberation time of music sound field [4], and also in varying the period of a flickering light [5].

In our previous study on the relationship between EEG alpha waves and subjective preference with changes of the period of a flickering light, the values of τ_e were longest in the occipital area [5]. In the present study, however, the values of τ_e were longest not in the occipital area but in the posterior temporal area. This may be a result of experimental conditions; the use of a fixed LED in the previous experiment compared to use of visual motion stimuli in this experiment. There have been reports on the existence of an area within the human visual cortex specialized in processing visual motion, V5 (MT). A recent study using human positron emission tomography (PET) found that area V5 is located at the occipital-temporal-parietal border [10]. The processing of visual motion stimuli in the human visual cortex area V5 has been investigated using PET, magnetoencephalography (MEG), and EEG. In a previous EEG study, it was found that the locations of cortical activation during the presentation of motion stimuli were more lateral than the activation during the presentation of pattern-reversal (non-motion) stimuli [11].

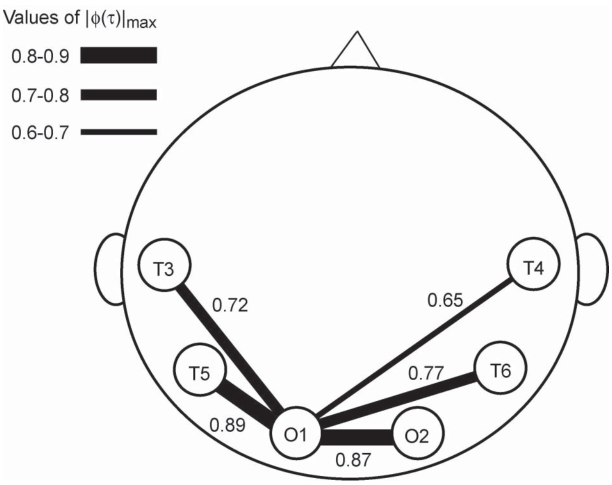

Fig. 8. The degree of correlation between O1 and the test electrodes during the presentation of stimuli with a period of 1.0 s in pair 1. The thickness of the bars indicates the range of the values of $|\phi(\tau)|_{max}$.

4.2. Values of $|\phi(\tau)|_{max}$ in the alpha range

A significant effect of the stimulus condition on the values of $|\phi(\tau)|_{max}$ was observed in the alpha range, but not in the theta or beta ranges. The averaged $|\phi(\tau)|_{max}$ values in the alpha range for the stimuli with the period of 1.0 s were significantly greater than for stimuli with periods of 0.4 or 4.0 s, as shown in Fig. 7. As these results were found for both pairs, we believe that the values of $|\phi(\tau)|_{max}$ in the alpha range were affected by subjective preference and not by the period (velocity) of stimuli. The values of $|\phi(\tau)|_{max}$ in the alpha range show a similar influence due to the presence of common alpha wave components, when examining the signals from the comparison and the test electrodes. Accordingly, the relationship between the values of $|\phi(\tau)|_{max}$ obtained at the cortical sites indicates a cortical propagation pattern (spatial behavior) originating from the comparison electrode (O1). The fact that the alpha waves have greater $|\phi(\tau)|_{max}$ values shows that the brain repeats its rhythm in the spatial domain over a wider cortical area in the preferred rather than the less preferred condition. This tendency toward greater $|\phi(\tau)|_{max}$ values in the alpha range was also found in our previous study on the effects of varying the period of a flickering light [6]. The study has examined the values of $|\phi(\tau)|_{max}$ in the delta, theta, alpha and beta ranges, and has revealed that $|\phi(\tau)|_{max}$ values were significantly greater only in the alpha range under the presentation of the stimulus with the preferred period.

As Figs. 7 and 8 show, the values of $|\phi(\tau)|_{max}$ are greater in the posterior temporal and occipital areas (T5, O2, respectively) than in the other areas. The figures show that the more lateral the cortical sites were, the smaller the values of $|\phi(\tau)|_{max}$ were for both pairs. It is considered that this tendency depends on the position of the comparison electrode and not of the scale values of subjective preference. In the present study, because O1 (the occipital site) was chosen as the comparison electrode, the values of $|\phi(\tau)|_{max}$ decreased as the distance between O1 and the other electrodes increased. These results were seen not only in the alpha but also in the theta and beta ranges. Previous study investigated the relationship between the signals at different cortical sites in rats to reveal the mechanisms of widespread synchronization of brain activity, and showed that the strength of association between the cortical sites decreased as a function of distance between the sites [12]. These tendencies were reconfirmed in our previous study [6].

5. CONCLUSIONS

We analyzed EEGs to determine the relationship between human brain response and subjective preference for horizontal visual motions of a movement over varying periods and obtained results regarding (1) temporal and (2) spatial features of the brain.

(1) The values of τ_e in the alpha range for stimuli with the most preferred period of the movement were significantly longer than stimuli with the less preferred period.

(2) The values of $|\phi(\tau)|_{max}$ in the alpha range for stimuli with the most preferred period were significantly greater than for stimuli with the less preferred period.

These results indicate that the brain repeats the rhythm in the alpha range, and that this activity spreads wider over the human brain cortex as a result of the presentation of stimuli with preferred motion rather than with less preferred motion.

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