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Spatial Focalization of Zen-Meditation Brain Based on EEG

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Abstract

The aim of this paper is to report our preliminary results of investigating the spatial focalization of Zen-meditation EEG (electroencephalograph) in alpha band (8-13 Hz). For comparison, the study involved two groups of subjects, practitioners (experimental group) and non-practitioners (control group).

To extract EEG alpha rhythm, wavelet analysis was applied to multi-channel EEG signals. Normalized alpha-power vectors were then constructed from spatial distribution of alpha powers, that were classified by Fuzzy C-means based algorithm to explore various brain spatial characteristics during meditation (or, at rest). Optimal number of clusters was determined by correlation coefficientsof the membership-value vectors of each cluster center.

Our results show that, in the experimental group, the incidence of frontal alpha activity varied in accordance with the meditation stage. The results demonstrated three different spatiotemporal modules consisting with three distinctive meditation stages normally recognized by meditation practitioners. The frontal alpha activity in two groups decreased in different ways. Particularly, monotonic decline was observed in the control group, and the experimental group showed increasing results. The phenomenon might imply various mechanisms employed by meditation and relaxation in modulating parietal alpha.

Key words : zen-meditation EEG, alpha distribution, wavelet transform, fuzzy c-means, spatial focalization.

I. INTRODUCTION

Meditation, classified as the category of *mind-body* intervention in complementary and alternative medicine (CAM), has been widely practiced on a daily basis for maintaining good health. Numerous studies have reported the physiological and psychological effects of meditation. Scientists have corroborated that meditation considerably lowered down the levels of respiration rate, heart rate, spontaneous skin conductance response and cortisol[1,2]. Other researches reported that meditation was useful in treating some medical problems such as hypertension[3,4], anxiety[5], pressure[6], and even tumors[7]. In psychoneurology, EEG becomes an important tool to monitor the meditation effects on the neural systems. A thorough review of researches on meditation EEG can be found in[8]. According to those literatures, the most common phenomenon is the increase of alpha-band power and alpha coherence in the frontal areas[9,12].

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Alpha activities are normally recorded on the posterior scalp regions for normal, healthy adults with eye-closed relaxation under conditions of physical relaxation and relative mental inactivity. In Cantero et al.'s research, they concluded that alpha rhythm could be the baseline of brain activity when sensory inputs are very few at the state of relaxed wakefulness [13]. Cantero et al. provided evidence for the alpha power modulation and different scalp distributions at a particular cerebral arousal state[15]. Correlation between cognition and alpha variation during meditation was studied by some researchers. Aftanas and Golocheikine claimed that turning off external attention during meditation reflected the increasing power of slow alpha in the frontal areas[9]. Since alpha variations are the common characteristic during meditation, investigation of alpha spatial-temporal traits is important for further understanding the neural-physiological effects of meditation.

Among various meditation techniques, we focus on Zen meditation that has been becoming popular in Taiwan. During meditation, meditators first transcend their physical and mental perceptions via particular mind-focusing technique, leave off the message transmission from outside world, and concentrate their attention on some particular Chakras[16].

Exploration of the meditation alpha activities has been focused on the change of alpha power and coherence, with few studies on the spatial-temporal behavior. Owing to the particular cognitive significance of alpha rhythms, investigating the distribution of alpha band might help understanding the meditation effects on the cortical activation. The aim of this study is thus to investigate the temporal evolution of spatial characteristics of alpha rhythms under Zen meditation.

In the following section, we introduce the methods for multi-channel meditation EEG processing and analysis, including wavelet transform for identifying alpha-dominated sections and Fuzzy C-means for classifying the feature vectors that represent the spatial distribution of alpha rhythms. Finally, we discuss the difference of spatial characteristics between experimental group (Zen meditators) and control group (non-meditators).

II. METHODS

A. Wavelet Transform

Spectrum analysis based on Fourier Transform (FT) has been the most popular method for identifying various EEG rhythms. However, FT can not resolve the time-varying spectral properties of EEG. Wavelet Transform (WT) is one of the approaches developed to solve the problem[17]. WT decomposes a signal into scaled, time-shifted version of the pre-designed wavelet prototype. WT possesses the capability of local analysis as well as high flexibility in terms of scalability in resolution. However, choosing an appropriate wavelet prototype is always the issue firstly encountered. A rational thought is to choose a wavelet model with its pattern matching the shape of the component to be analyzed. Accordingly, the wave shape of Daubechies 6 (Db 6) low-pass filter was selected in this study. Furthermore, Daubechies wavelets are used due to their properties, including good regularity for high number of moments[25]

B. Alpha Detection

A number of alpha detection algorithms have been developed in both time and frequency domains. Due to the time-varying spectral behavior of alpha patterns, a wavelet-based algorithm becomes appealing for alpha detection.

To decompose the EEG, discrete wavelet transform (DWT) was implemented by the typical pyramidal structure (order 2), with a window size of 1 second and no overlap. We then calculated the wavelet coefficients corresponding to the delta (δ: 3.5 Hz or less), theta (θ: 4~7.5Hz), alpha (α: 8~13 Hz), beta (β: 14~30 Hz) and gamma (γ: above 30 Hz) band. Finally, EEG rhythm in each particular band was reconstructed. Define the alpha-power percentage below,

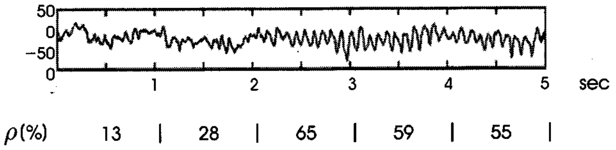

Fig. 1. A 5-sec EEG. The numbers listed below are the alpha-power percentages

$$\rho = \frac{P_\alpha}{P_\delta + P_\theta + P_\alpha + P_\beta + P_\gamma} \times 100\% \qquad (1)$$

where P_α denotes the power of the reconstructed wave, and so on.

Consider an EEG epoch. If the alpha-power percentage ρ is greater than a pre-defined threshold θ_1 (θ_1=50% in this study), it is considered as an alpha-dominated epoch. Fig. 1 displays alpha-power percentages varying with time.

From Fig. 1, alpha apparently dominated the last 3 seconds (ρ> 50%), that were to be extracted for further spatial analysis. All the 30-channels were examined to identify the alpha-dominated epochs. Those epochs with at least one channel satisfying ρ>50% were extracted. Next the alpha- power vector is defined as

$$P_{\alpha i} = [P_{\alpha i1} \quad P_{\alpha i2} \quad P_{\alpha i3} \quad \cdots \quad P_{\alpha i30}] \qquad (2)$$

where $P_{\alpha i}$ is a vector containing the 30-channel alpha powers for the i^{th} epoch, with its element $P_{\alpha ij}$ representing the alpha power of the j^{th} channel. Final feature vector was obtained by normalizing the alpha-power vector based on the pool of all vectors extracted.

C. Fuzzy C-means

Fuzzy c-means (FCM) is a data clustering method wherein each data point belongs to a cluster to some degree specified by a membership value[18]. We utilized FCM to classify the input feature vectors (normalized alpha-power vectors). In FCM, number of clusters needs to be determined first. We proposed the idea of evaluating correlation coefficients to estimate the appropriate number of clusters. First, with an initial guess (>5), we can derive the membership value for each sample x_j:

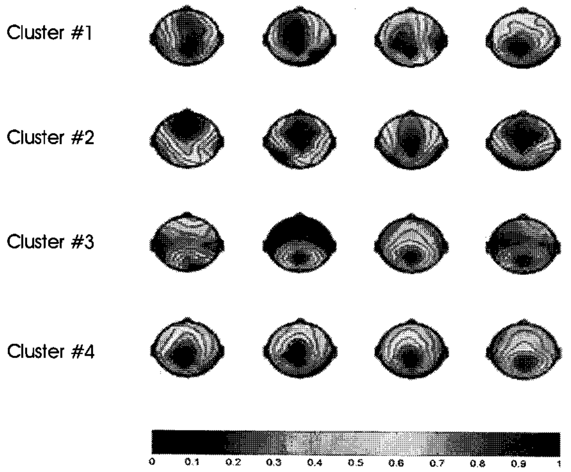

Fig. 2. The results of 4 clusters

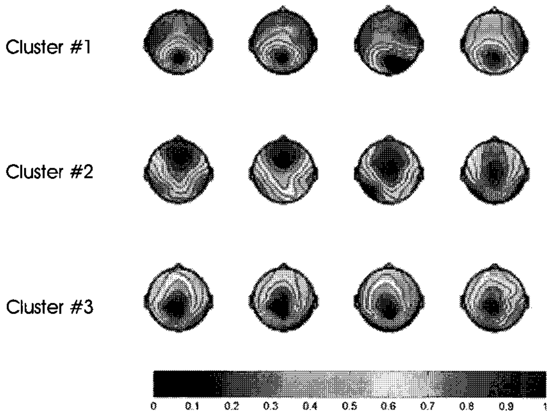

Fig. 3. The results of 3 clusters

$$x_{ij} = \left[\sum_{l=1}^{c}\left[\frac{d_{ij}}{d_{lj}}\right]^{\frac{2}{\beta-1}}\right]^{-1} \tag{3}$$

where x_{ij} is the membership value of sample x_j with the center y_j, d_{ij} is the distance between x_j and y_i, c is the number of clusters, and β is the fuzziness coefficient. Each center y_i has its membership-value vector,

$$x_i = \begin{bmatrix} x_{i1} & x_{i2} & \cdots & x_{im} \end{bmatrix} \tag{4}$$

Here m is the number of extracting vectors. The correlation coefficient is

$$R(x_i, x_j) = \frac{C(x_i x_j)}{\sqrt{C(x_i, x_i)\, C(x_j, x_j)}} \tag{5}$$

where $C(x_i, x_j) = E[(x_i - \mu_i)(x_j - \mu_j)]$ is the covariance matrix.

If $R(x_i, x_j)$ is larger than the threshold θ_2 (in statistical reason, we set $\theta_2 = 0.3$ for the side line between strong and weak correlation), y_j and y_i are too close, and the number of cluster c must be reduced by 1.

First we checked the performance of our algorithm by analyzing 800 real EEG epochs. Normalized alpha-power vector is illustrated by colored brain mapping. Fig. 2 displays the results of classifying the alpha-power mappings into 4 clusters. Note the horizontal bar represented the range of the normalization results, and the range is 0 to 1. Table 1 lists the correlation coefficients between clusters i and j, $1 \leq i, j \leq 4$ (assume 4 clusters).

Apparently, mappings in cluster #1 are very similar to those in cluster #2, and a large correlation coefficient $R(x_1, x_2)$ =0.67 is obtained. Accordingly, number of clusters should be reduced. Fig. 3 shows the results of 3 clusters. Table 2 shows the correlation coefficients for the 3-cluster case. Note that none of these coefficients exceeds θ_2, that indicates the number of clusters c=3 is appropriate for the sample pool analyzed. The example above demonstrates the strategy of determining the appropriate number of clusters. Flowchart of the algorithm is shown in Fig. 4.

D. Subjects and Recording Setup

This study involved 10 experimental subjects (Zen meditators) and 10 control subjects (normal, healthy people without any experience in meditation). Experimental group

Table 1. The correlation coefficients (4 clusters)

Cluster	1	2	3	4
1		0.67	−0.86	−0.32
2	0.67		−0.73	−0.64
3	−0.86	−0.73		0.04
4	−0.32	−0.64	0.04	

Table 2. The correlation coefficients (3 clusters)

Cluster	1	2	3
1		−0.80	−0.51
2	−0.80		−0.11
3	−0.51	−0.11	

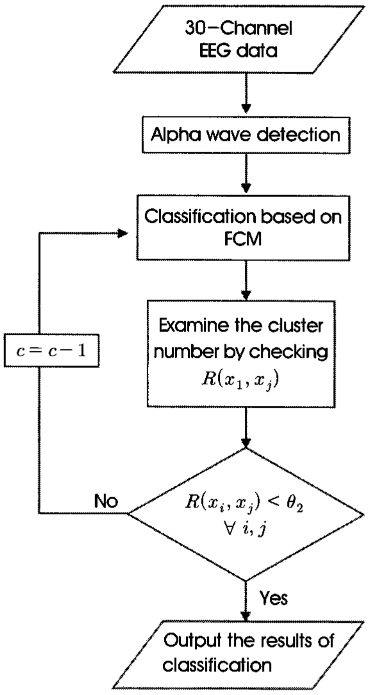

Fig. 4. Flowchart of the proposed algorithm

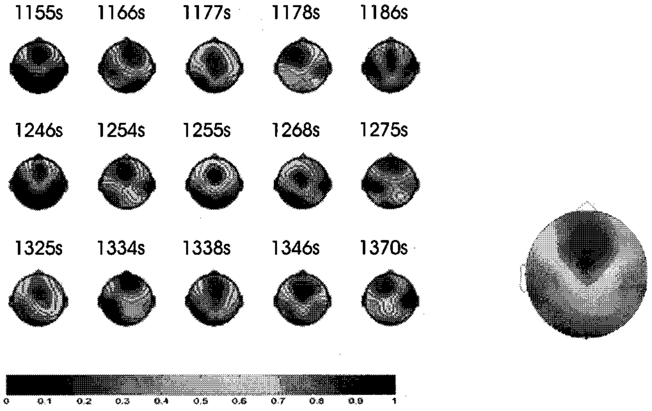

Fig. 5. Selected samples (three rows) and the center of Cluster #1. The numbers above the samples are the time indices (in sec)

included 3 females and 7 males at the average age of 28.9±3.2 years. Their experiences in Zen-Buddhist practice span 7.6±4.5 years. Control group consisted of 4 females and 6 males at the average age of 25.9±5.2 year.

EEG was recorded within the frequency range from 0.15Hz to 50Hz, with a sampling rate of 512 Hz. We applied the 30-channel recording montage, based on the 10-20 system, with the ground at the forehead and the linked mastoids as the reference.

Subjects sat in an isolated space during the recording. Each recording lasted for about 34 minutes, including 2-minute pre-session, 30-minute main-session, and 2-minute post-session recording.

In the main-session period, experimental subjects practiced the Zen meditation, while control subjects sat in normal, relaxed position with eyes closed. During the meditation, experimental subject sat in the full-lotus or half-lotus position, with eyes closed. While before and after the main-session period, both experimental and control subjects closed their eyes and relaxed.

Ⅲ. RESULTS

A. The results of classification

Figs. 5 to 7 plot the results for one experimental subject (cluster number c=3). Totally 709 alpha-power vectors were detected and analyzed. Only a portion of alpha-power brain mappings are displayed for each cluster.

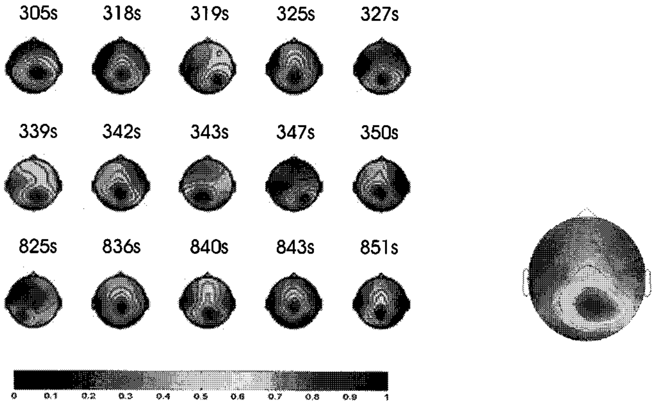

Fig. 6. Selected samples (three rows) and the center of Cluster #2. The numbers above the samples are the time indices (in sec).

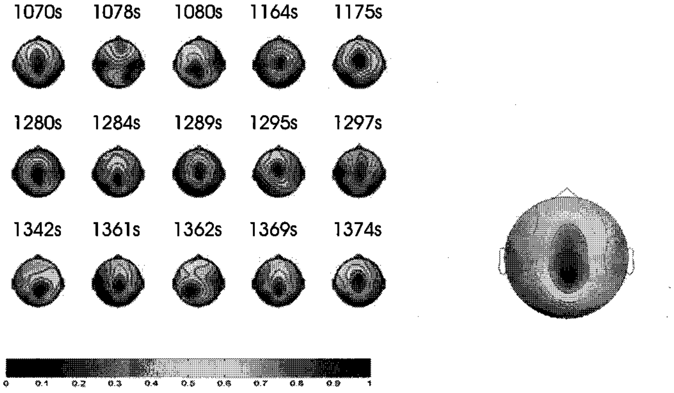

Fig. 7. Selected samples (three rows) and the center of Cluster #3. The numbers above the samples are the time indices (in sec).

Table 3. The Euclidean distances between cluster centers

Cluster \ Cluster	1	2	3
1		1.474	0.765
2	1.474		0.895
3	0.765	0.895	

Table 4. The standard deviation of the distances of each sample to its center

Cluster	Number of samples	Standard deviation of the distances
1	266	0.250
2	246	0.232
3	197	0.242

B. Performance of FCM

Table 3 lists the Euclidean distances between different cluster centers. Standard deviation of the distances of all vectors away from the cluster center is computed for each cluster(Table 4). According to Tables 3 and 4, distances between cluster centers are greater than three times of the standard deviations. Evidently, FCM successfully separated these clusters.

C. Color-chart representation of alpha spatiotemporal evolution

To investigate the spatiotemporal evolution of alpha activities, we employed the color-chart illustrationwith red, blue and green indicating the emergence of brain mappings belonging to cluster #1, #2 and #3, respectively. Black indicates the non-alpha epochs. Fig. 8 plots the color chart of alpha distribution for one meditator (Fig. 8(a)) and one control subject (Fig. 8(b)).

From this chart, we could assess the alpha distribution easily. For instance, we could find frontal alpha (class #1) emerged more often in the middle and non-alpha presented in the late phase of the main-session. The statistical analysis of spatiotemporal distribution of alpha activities for both groups will be discussed in the next section.

D. Comparison of two groups

To investigate the focalization of alpha activity, we divided the scalp into six areas (Fig. 9) representing six categories. The classification was based on 'peak' location since it reflected the source focalization[23].

We calculated the *incidence* of each category based on a 2-minute frame. The window size was 2 seconds and no overlap between successive windows. Accordingly, *incidence* measures the probability of peak focalization at the same area based on 60's 2-sec epochs. The formula is shown below.

$$incidence = \frac{\text{Number of epoch belong to the category}}{\text{Total epochs in 2-min (60epochs)}} \qquad (1)$$

We emphasized on the frontal, central and parietal areas where alpha activities frequently appear. Fig. 10 to 12 show the time-varying probabilities of focalization, respectively, in the frontal, central and parietal region of both groups. Beginnings of the main and the post session were marked by vertical dashed lines at the 2nd and 32th minute. The value at the nth minute was the group average of results analyzed for 10

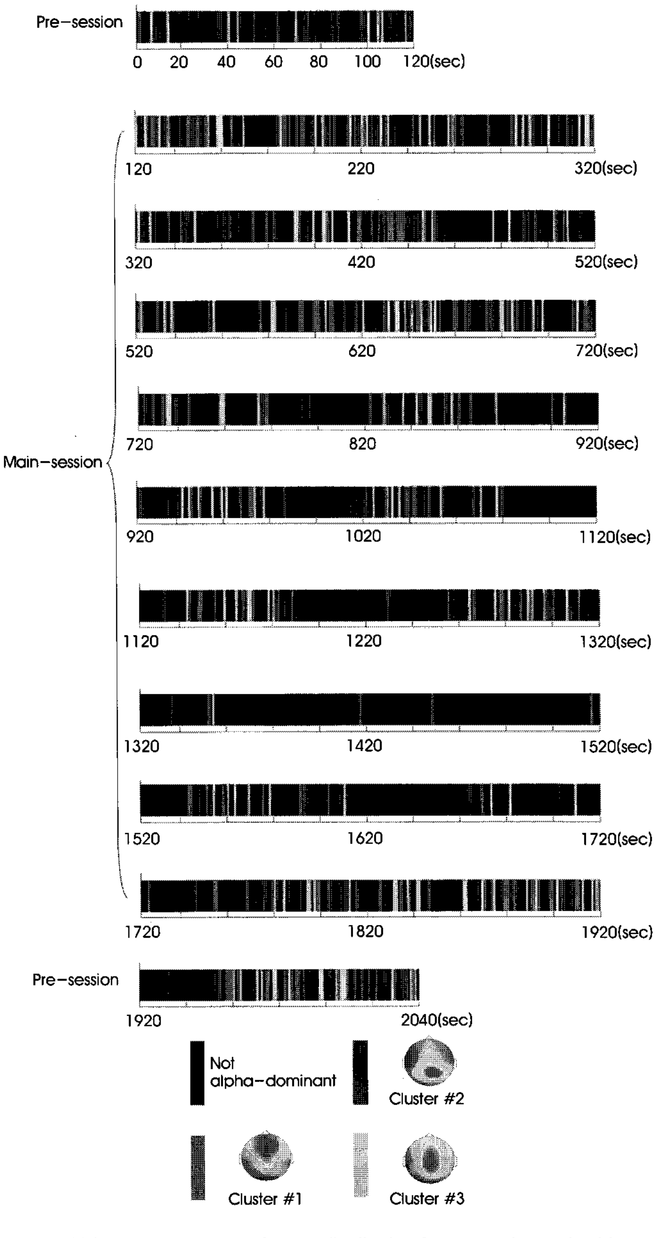

Fig. 8(a). The color chart of alpha distribution for a experimental subject

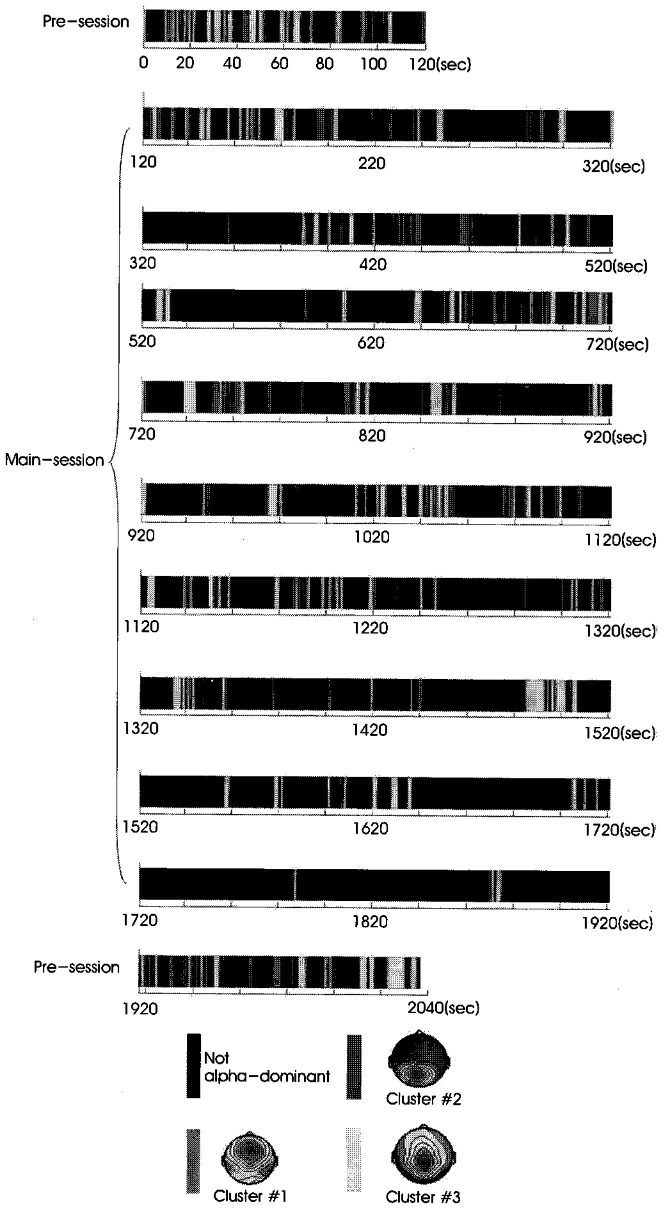

Fig. 8(b). The color chart of alpha distribution for a control subject

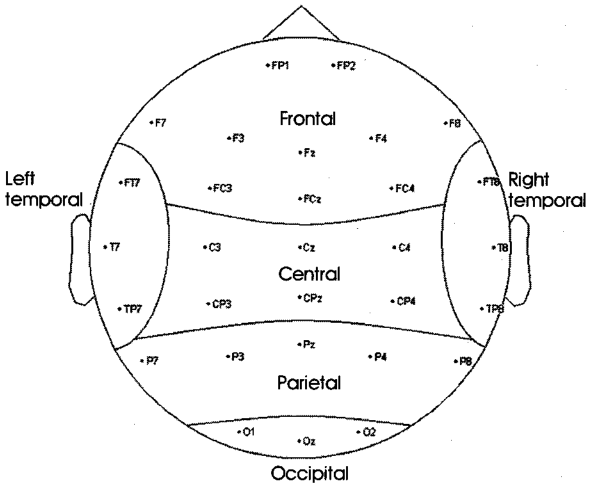

Fig. 9. The locations of 30 recording electrodes and their respective region.

subjects in each group, using the 2-min frame between (n-1)th and (n+1)th minute. For each category (area), *incidence* in the 2-min frame was compared with the pre-session result using *t-test* to evaluate the statistical significance of difference caused by meditation process. The asterisks on the top of the chart indicate the statistically significant difference ($p<0.05$) at those time points. For example, significant effect of meditation (relaxation) on frontal alpha was observed at the 25th minute for the experimental(control) group.

Incidence of frontal alpha of the experimental group oscillates noticeably during the entire recording session, as shown in Fig. 10, with an increase in the early meditation phase (3-13 minutes) followed by a dramatic drop afterwards (13-17 minutes). However, in the later phase of meditation the frontal alpha was increasing again (17-25 minutes). On the other hand, control group exhibited quite different results with decreasing frontal alpha in the entire main session. In addition,

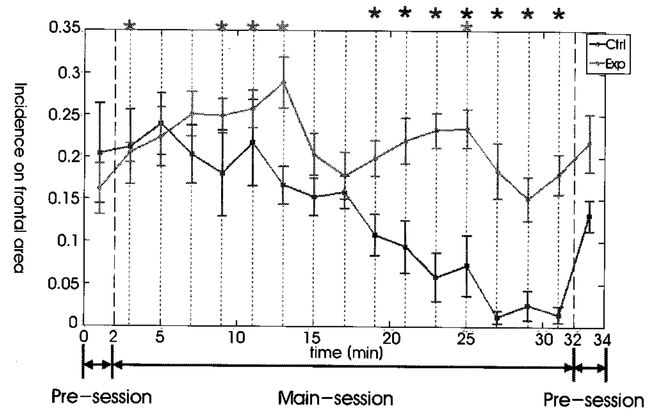

Fig. 10. The incidence of frontal alpha of both groups.

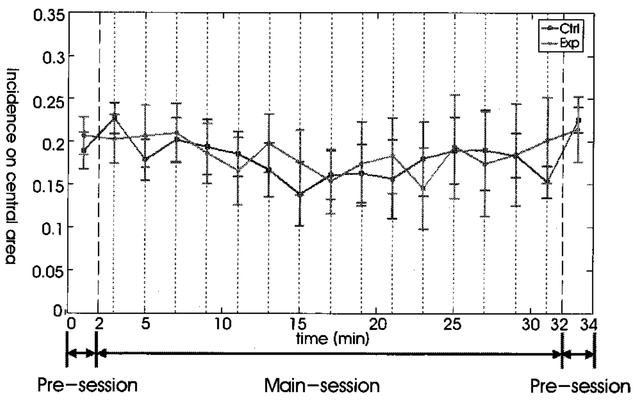

Fig. 11. The incidence of central alpha of both groups.

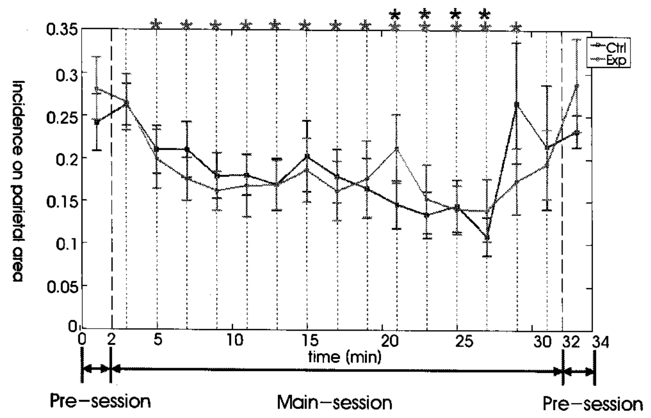

Fig. 12. The incidence of parietal alpha of both groups.

statistically significant difference of frontal-alpha incidence between group averages was observed by t-test ($p < 0.01$).

Fig. 11 displays the group averages of incidence variations of central alpha. Apparently, both curves show the similar trend for the entire recording session, that is, a slight reduction of central-alpha incidence during the main session following by an increase in the post session. As regards the spatio-temporal features of parietal alpha, incidence of the experimental group declined from the beginning of meditation and maintained till the end of meditation session (Fig. 12). In the control group, the incidence presented a continuing decay in the whole relaxation session. Although these two groups showed similar trend, the consistency within each individual group was quite different. The experimental group revealed constant decrease in parietal alpha and showed significant difference at the early stage of meditation (5th minute), that was not observed in the control group until the 21th minute of main session.

Ⅳ. CONCLUSION AND DISCUSSION

In this study, we developed a scheme to investigate the spatiotemporal behavior of alpha power in Zen-meditation practitioners. Consistent increase of frontal alpha in the beginning of meditation can be recognized as the major distinction between meditation and relaxation. According to the post-experimental interview, they calmed down their mind and shut off their sensors to the outside stimuli by concentrating their attention on a specific chakra. Such inward attention conduct may result in the increase of frontal alpha [9]. In fact, advanced brain imaging technologies have verified such meditation experiences that had been considered 'putative' for long[26,27].

The enhancements of alpha power are associated with lower-level anxiety and positive feelings of calm[28-31]. Lower alpha in the frontal region was found to be associated with the process of external attention such as alertness or vigilance[32,33]. During meditation, practitioners often begin withdrawing their attention to the external environment that might be one of the reasons of increasing frontal alpha power.

As meditation was underway, frontal alpha decreased notably that signified the possibility of consciousness transition to the state of awareness of the inner energy[16]. In some researches, this phenomenon might be related to the transcendental experience[34,35]. They found, at this meditation stage, EEG exhibited relatively large ratio of beta activities that correlated with different consciousness during Zen meditation.

While practitioners entered the next meditation stage, they often perceived inner light and had the blissful feelings, with the sense of time and space fading away[21]. The frontal-alpha incidence increased in this state (about 17th ~ 25th minute). On the other hand, the attenuation of frontal alpha observed during last few minutes of meditation highly correlated with the fact that some practitioners returned to normal, attentive consciousness. Suppression of parietal alpha in both groups behaved quite the same. Nerberg et al.[22] reported that the decreasing parietal alpha in meditators was caused by the state of mind more imperceptible to the external stimulus. Come control subjects fell drowsiness in the later half of relaxation session, causing the dropout of alpha activities[24]. Although both groups revealed decreasing parietal alpha, the mechanisms of modulating alpha are quite different.

To sum up, an important finding in this paper is the meditation states possibly inferred by alpha: mindful attention to reduce mental activities, transition to internal awareness, and "inner-light" perception, respectively. These findings correspond to the phenomenon that frontal alpha increases or decreases moderately.

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