Investigation of Visual Perception Under Zen-Meditation Based On Alpha-Dependent F-VEPs

Article · January 2006

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Industrial Technology Research Institute

J. Biomed. Eng. Res : 384-391, 2006

Investigation of Visual Perception Under Zen-Meditation Based On Alpha-Dependent F-VEPs

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(Received October 17, 2006. Accepted November 28, 2006)

Abstract

Variation of brain dynamics under Zen meditation has been one of our major research interests for years. One issue encountered is the inaccessibility to the actual meditation level or stage as a reference. In this paper, we propose an alternative strategy for investigating the human brain in response to external flash stimuli during Zen meditation course. To secure a consistent condition of the brain dynamics when applying stimulation, we designed a recording of flash visual evoked potentials (F-VEPs) based on a constant background EEG (electroencephalograph)frontal α-rhythm dominating activities that increase significantly during Zen meditation. Thus the flash-light stimulus was to be applied upon emergence of the frontal α-rhythm. The alpha-dependent F-VEPs were then employed to inspect the effect of Zen meditation on brain dynamics. Based on the experimental protocol proposed, considerable differences between experimental and control groups were obtained.Our results showed that amplitudes of P1-N2 and N2-P2 on Cz and Fz increased significantly during meditation, contrary to the F-VEPs of control group at rest. We thus suggest that Zen meditation results in acute response on primary visual cortex and the associated parts.

Key words : zen meditation, EEG, flash vep, autoregressive model, alpha rhythm

I . INTRODUCTION

A rapid increase in the use of CAM (complementary and alternative medicine) across the Western World has aroused attention of researchers. Zen meditation, classified as the category of mind-body intervention in CAM [1], has been widely practiced on a daily basis for maintaining good health. However, it still has not yet been completely understood by western medicine. To know more about its benefit to our body, a lot of researches have been devoted to the study of meditation process and phenomena, mostly in the physiological and psychological aspects. Scientific exploration has corroborated the effectiveness of meditation practice on the health promotion which includes regulation of the hormone-level and blood pressure, moderation of stress and anxiety, reduction of chronic pain, etc [2-8].According to the experienced practitioners, meditation facilitates a greater sense of calmness, empathy, and compassion. As Western medical practitioners begin to understand the role of mind in health and disease, there has been more interest in both employing meditation in medicine and exploring brain dynamical phenomena during meditation. Electroencephalogram (EEG) thus becomes an important tool to monitor the meditation process [7-13].

In recent years, we have been investigating the Zen meditation EEG in multi-faceted aspects. According to our long-term interactions with the experienced practitioners for several years, the Zen meditation process involves experience of transcending various physiological, mental, and conscious states as follows. A meditator would first attenuate their physical and mental sensors via particular mind-focusing technique, leave off the message transmission from outside world, and keep subconsciousness tranquil during meditation. Moreover, meditators often experience unusual perceptions, for example, loss or distortion of space and time perceptions, sensation of aureola-surroundings, etc. Especially, in the deeper meditation state, many meditators have experienced the perception of inner light [14].

Variations in EEG temporal and spatial activities have been presumed to be associated with the meditation stages, a comprehensive review was published recently [13]. Davison et al. found that long-term Buddhist practitioners self-induced sustained high-amplitude, gamma-band oscillations and phase-synchrony during meditation. These EEG patterns were

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noticeable especially at the lateral fronto-parietal electrodes [15-16]. In Zen-meditation EEG study, increased alpha activity over the frontal regions of the brain has been observed during meditation [17-18] and so has the increased frontal alpha coherence [19]. Kasamatsu and Hirai found an increase in alpha amplitude at the beginning of meditation, which then spread frontally [17]. Furthermore, Takahashi et al. observed that the increased frontal alpha power correlated with the enhancing internalized attention [18]. Thus increased frontal alpha activity was hypothesized as a result of Zen-meditation process. All the observations have led into further understanding of the function-correlated, spatial characteristics of the brain affected by meditation. Another topic of interest in the meditation study involves the evoked potentials (EP) (or event-related potentials, ERP) under meditation. These studies include auditory evoked potential (AEP), somatosensoryevoked potential (SEP), visual evoked potential (VEP), and so on. Each parameter is meaningful to the respective perception function. Zhang et al. [20] claimed that the amplitudes of F-VEPs (VEPs under flash stimuli) of Qigong meditators increased under meditation. In Xu et al.'s research [21], the amplitude of F-VEP increased while the latency decreased. They suggested that concentration and attention may be the reason of altering the evoked potentials.

Due to unusual perceptions often experienced during meditation, human brain in response to external flash stimuli during Zen meditation draws our attention. Recording of VEPs provides a means of characterizing the visual pathway and visual function. VEPs can be recorded by applying either patterned or non-patterned stimulus that results in various VEP waveforms [22]. Since practitioners must close their eyes during meditation, we employed non-patterned flashes in the VEP recording.

One problem encountered in the F-VEP study is to determine the appropriate timing for applying the flash-light stimulus. To our knowledge it has not been reported in regard to this issue. In our previous study, stimulus was applied at the mid-section of meditation at which subjects might undergo various physiological and mental states. In that case, F-VEPs were not able to reveal different experimental courses such as the section before, during, and after meditation [23]. To assure that all F-VEPs are acquired under a consistent condition, a rational experimental setup is to apply the stimulus based on a controllable factor. To gain access to particular brain states, one approach is to ask the subject to signal the attainment of the meditation state by finger movement [14][18][24]. However, it often causes meditators to break off from the meditation state.

To investigate the ERP activities in a given brain state defined by EEG, we thus conceive the idea of EEG-triggered F-VEP scheme, that is, the flash-light stimulus is applied under specific oscillatory features of the EEG. In this preliminary study, we intuitively select the frontal α-rhythm as the F-VEP triggered signal based on the previous results reviewed in this section and our empirical observations these years. The following section illustrates the methods for detecting the frontal α-rhythm and the experimental setup. Significant results obtained are discussed in section 3.

II. METHOD

According to the background description in Introduction, the flash-light stimulus is to be applied upon emergence of the frontal α-rhythm. The scheme proposed in [25] is based on the autoregressive (AR) spectrum estimation. It provides more accurate estimate with better resolution [26-27] and, in particular, allows on-line α-rhythm detection within a very small time frame. Modification of the scheme for on-line α-rhythm detection is described below.

A. Online α-rhythm Detection

EEG signal is first decomposed into subband components by the tree structural filter bank, as shown in Fig. 1. According to Gabor's uncertainty principle [28], downsampling operation improves frequency resolution which is desired for the narrow-band EEG. Moreover, downsampling process makes the AR modeling better characterize the low frequency activities [25]. We accordingly employ the subband-filtering scheme prior to the frequency analysis by AR modeling for better frequency resolution and lower computation load. A linear-phase lowpass FIR filter H(z) designed by using least-squares error minimization with cutoff frequency 30Hz is used as an anti-aliasing filter before the downsampling operation. Then the AR(2) model is applied to the decimated signal. Consider the EEG signal $x[n]$ generated by an autoregressive (AR(2)) process that is driven by the unit-variance white noise $w[n]$. An AR(2) model can be expressed as

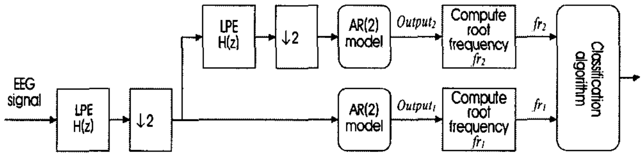

Fig. 1. Tree structural filter bank for the Subband-AR EEG Classifier. H(z) is designed by least-squares error minimization with cutoff frequency 30Hz.

$$x[n]+a_2[1]x[n-1]+a_2[2]x[n-2]=w[n]. \qquad (1)$$

The model coefficients $a_2[k]$ can be determined by solving the autocorrelation normal equations [26]. After the model coefficients have been obtained, the conjugated pole pair is determined as,

$$-\frac{a_2[1]}{2}\pm j\frac{\sqrt{4a_2[2]-a_2{}^2[1]}}{2} \qquad (2)$$

Thus the root frequency of the signal can be obtained from Eq. (2)

$$f_{r,i}=\angle\left(-\frac{a_{2,i}[1]}{2}+j\frac{\sqrt{4a_{2,i}[2]-a_{2,i}{}^2[1]}}{2}\right) \qquad (3)$$

where i denotes the i^{th} decomposition level. The filtering-and-downsampling process is reiterated to attain good accuracy in discriminating between α and δ/θ rhythms. The equivalent cutoff frequency is 15Hz. We design a criterion based on the root frequency to detect the α-rhythm. The algorithm examines each windowed segment to check whether it meets the following criterion.

Criterion - α: 7Hz $< f_{r,1} <$ 14Hz and 7Hz $< f_{r,2}$.

The root frequency $f_{r,1}$ is used to differentiate EEG rhythms in 014Hz from those in 14-30Hz. Next, root frequency $f_{r,2}$ is examined to screen out δ/θ rhythms.

Note that output_1 and output_2 are the results of downsampling (Fig. 1), the root frequency $f_{r,i}$ should be further divided by 2^i. This experiment employs a window length of 1 second, with a moving step of 0.5 second.

Simulation

To verify the effectiveness of the α-rhythm detection algorithm, the algorithm is firstly applied to a simulated signal. We assume the sampling rate is 128Hz. The signal can be simulated by the pole placement method, that is, by placing each pole in the corresponding frequency band (Table 1) and adding Gaussian noise. As displayed in Fig. 2(e), the simulated 10-second signal is formed by connecting four segments of δ, θ, α, and β-rhythm patterns. Detection result in Fig. 2(e) is illustrated by two gray scales, with dark (light) gray indicating the α(non-α) pattern. The result clearly justifies the effectiveness of the algorithm in α detection.

Table 1. Locations of poles of the simulated signal

	δ	θ	α	β
Poles' location	0.98∠0.04	0.98∠0.16	0.98∠0.4	0.88∠0.63

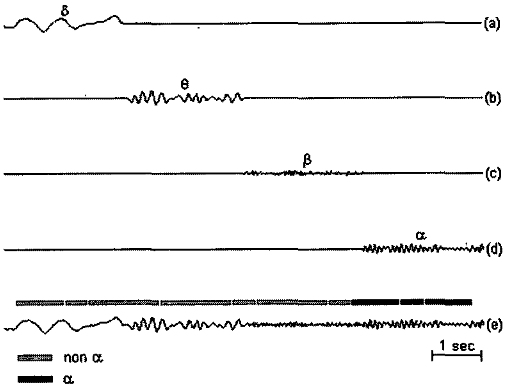

Fig. 2. Classification result of the simulated signal. Different grays are used to illustrated theαand non-α patterns.

Off-Line Alpha Detection

Empirical EEGs often exhibit highly complex, irregular rhythmic patterns that make the recognition of specific EEG pattern more difficult. Our algorithm is robust in dealing with this kind of complication. Fig. 3 displays the result of α detection. The error rate, estimated from the results of identifying 780 alpha candidates, was approximately 7.2% (4.6% false negative and 2.6% false positive rate) in comparison with the results of naked-eye examination by an experienced EEG interpreter.

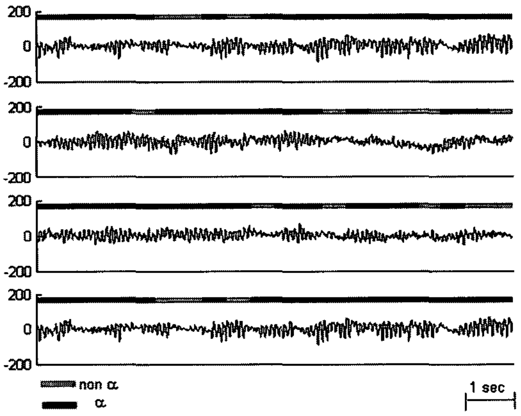

Fig. 3. Result of α detection for real EEG signal.

B. F-VEP

The F-VEP consists of a series of negative and positive peaks, denoted respectively by N and P followed by a number. The number is referred to as the order (or time) of occurrence of that particular peak from the stimulus. The F-VEP source is located in the occipital lobe. Normally, the event-related brain potentials propagate via neural network toward the nearby regions. The phase differences among different channels are caused by the time delays of brain-wave propagation [31].

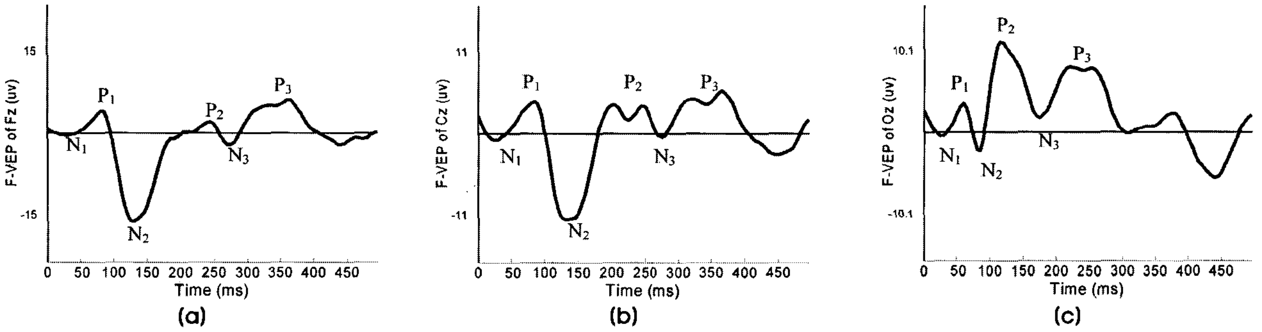

Fig. 4. Profile of F-VEPs on (a) Fz, (b) Cz, and (c) Oz with corresponding peaks labeled.

Fig. 4 shows typical F-VEPs recorded on Fz, Cz,and Oz with corresponding peak labels. In this study, peaks of significance including N2, P2, N3, and P3 are to be analyzed. Note that F-VEPs of different channels have phase deviation.

Researchers inferred that the noticeable negative peak N2 of Oz was generated in lamina IV cb [29-30], then the following positive peak P2 might reflect the inhibition activity within lamina. This study is mainly based on the hypothesis that Zen meditation affects visual neural pathway that can be revealed on the F-VEPs.

C. Experimental Setup

Subjects

This study involves 11 meditators and 11control subjects. In the experimental group, 4 females and 7 males at the mean age of 27.5 ± 3.2 years participated. Their experiences in Zen-Buddhist practice span 5.5 ± 4.3 years. The control group includes 3 female and 8 male students with an average age of 23.6 ± 3.3 years.

Apparatus

The EEG signals and F-VEPs were recorded at standard 10/20 positions with 32-channel SynAmps amplifiers (manufactured by NeuroScan, Inc.) connected to a Pentium-4 (1.5 GHz) PC. Common reference of linked MS1-MS2 (mastoid electrodes) was used. EEG signals, after amplification, were pre-filtered by a bandpass filter with passband 0.3-50 Hz, and digitized at 1000 Hz sampling rate. A 60-Hz digital notch filter was applied to the data to remove artifacts from power line or the surroundings.

We developed an online α-detection algorithm that was implemented by using g.BSamp with g.RTsys (manufactured by Guger Technologies, Inc.) connected to a Pentium-M (1.4 GHz) notebook. g.BSamp is a stand-alone biosignal amplifier and g. RTsys is a biosignal acquisition and real-time analysis system for notebook implementation. To facilitate the real-time α detection, channel-Fz EEG was pre-filtered by a bandpass filter with passband 0.5-30 Hz, and digitized at a lower rate of 128 Hz. The α-detection algorithm was implemented on Simulink (MathWorks, Inc.,Natick, MA) with Real-Time Workshop. By generating real-time code with Real-Time Workshop, the algorithm can be downloaded to the kernel and run in a real-time manner under Windows [32]. The experimental setup is shown in Fig. 5. The subject stayed in an isolated space. A CCD camera positioned in front of the subject was used to monitor the entire procedure. The 32-channel EEG signals were recorded by an EEG recording system. Another computer read channel Fz simultaneously to identify the occurrence of frontal α - rhythm. Once the frontal-α was ascertained, the computer triggered the flash light controller to generate flash stimuli.

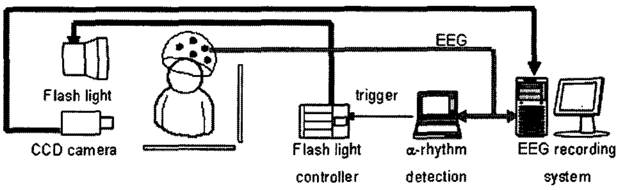

Fig. 5. Experimental setup for α-dependent F-VEP recording.

Experimental Paradigms

During the experiment, subjects sat in a separated space in the laboratory. Each recording lasted for about 60 minutes, including three sections: two 10-minute background EEG recordings (section I and III) before and after a 40-minute recording (section II, the "main section") of EEG under meditation (experimental subject) or rest (control subject). The control subject sat in a normal, relaxed position with eyes closed, while the meditators practiced Zen-Buddhist meditation during the 40-minute main section. In Zen meditation, the subject sat, with eyes closed, in the full-lotus or half-lotus position. Each hand formed a special mudra (called the Grand Harmony Mudra), laid on the lap of the same side. The subject focused on the Zen Chakra and the Dharma Eye Chakra (also

Table 2. The changes in the peak amplitudes of specific F-VEP components.

	Item	Exp group			Ctrl group			t-test	
		II/I (%)	III/II (%)	P value (paired t-test)	II/I (%)	III/II (%)	P value (paired t-test)	II/I	III/II
Oz	P1-N2	95.09	114.40	NS	141.63	114.31	NS	0.013*	NS
	N2-P2	101.41	101.44	NS	121.07	103.60	NS	0.010*	NS
	P2-N3	107.10	102.77	NS	112.20	122.49	NS	NS	NS
	N3-P3	117.33	106.86	NS	90.59	114.25	NS	NS	NS
	P3-N4	121.35	104.18	NS	112.71	81.89	NS	NS	0.035*
Cz	P1-N2	106.25	76.33	0.057	81.20	87.08	NS	0.043*	NS
	N2-P2	120.10	89.18	0.00037*	93.64	102.01	NS	4.78E-05*	NS
	P2-N3	134.73	103.43	NS	124.25	135.75	NS	NS	NS
Fz	N1-P1	126.68	97.03	NS	104.30	125.79	NS	NS	NS
	P1-N2	119.20	86.72	0.056	87.02	95.01	NS	0.043*	NS
	N2-P2	115.70	92.76	0.040*	88.77	110.03	0.052	0.0025*	0.045*
	P2-N3	143.35	128.01	NS	99.77	119.34	NS	NS	NS

I: section I, II: section II (main section), III: section III,
*: P<0.05,
NS: Not Significant

known as the "Third Eye Chakra") in the beginning of meditation till transcending the physical and mental realm. The Zen Chakra locates inside the third ventricle, while the Dharma Eye Chakra locates at the hypophysis [14].

The term "alpha-dependent F-VEPs" was used because we recorded F-VEPs upon the detection of frontal α rhythms. One run of alpha-dependent F-VEPs were recorded in each of the three sections (Fig. 6). Each run consisted of 50 alpha-dependent flash stimuli. The interval between two consecutive stimuli was longer than 1 sec. The flash light, with a $10\mu s$ duration, was produced by a xenon lamp that was placed 60 cm in front of the subjects' eyes. Alpha-dependent F-VEPs were acquired from midline channels Oz, Cz and Fz, with the linked-mastoid electrode as the reference. Since we employed the mastoid-referenced unipolar montage, alpha activities could be found in the frontal channels of all subjects [33]. However, more frontal alpha activities were detected during meditation, that reduced the time required for collecting 50 alpha-dependent F-VEPs.

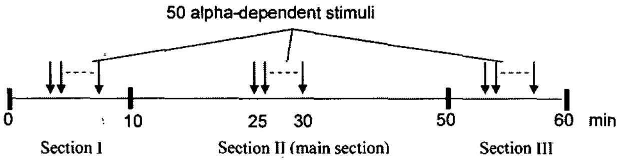

Fig. 6. Scheduling of the F-VEP recording procedure.

III. RESULTS

As shown in Fig. 7, different codes were used to indicate the stimuli presented in different sections. The stimuli in section I, II, and III are marked by code 128, 64, and 32, respectively. And the marker at the upper left of each code indicates the time of flash stimulation. A concluding F-VEP of each section was derived by averaging 50 raw tracings in one run.

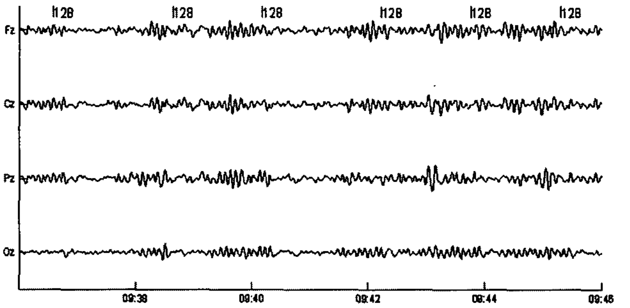

Fig. 7. Display format of selected channels (Fz, Cz, Pz, and Oz) for α -dependent F-VEP recording. The vertical bar at the upper left of mark '128' indicates the time of applying flash stimulus.

Inter-subject variations of human VEP under the open experimental environment are complicated. We thus investigated the intra-subject differences among various sections conducted in one experiment. We measured the amplitude and latency of the average F-VEP, and quantified the difference between various sections. Our results presented quite different trends between two groups. Fig. 8 plots an example of the F-VEPs at Fz, Cz and Oz (from the top) for one subject. The solid lines represent the F-VEPs in the section I, and the dash and dot ones stand for those in the section II and III.

From our results we found that latencies of all components exhibit no significant difference among all sections in both groups. However, the variations of amplitudes show differences in some components between two groups. Table 2 presents, for each F-VEP component, ratios of the group average amplitudes

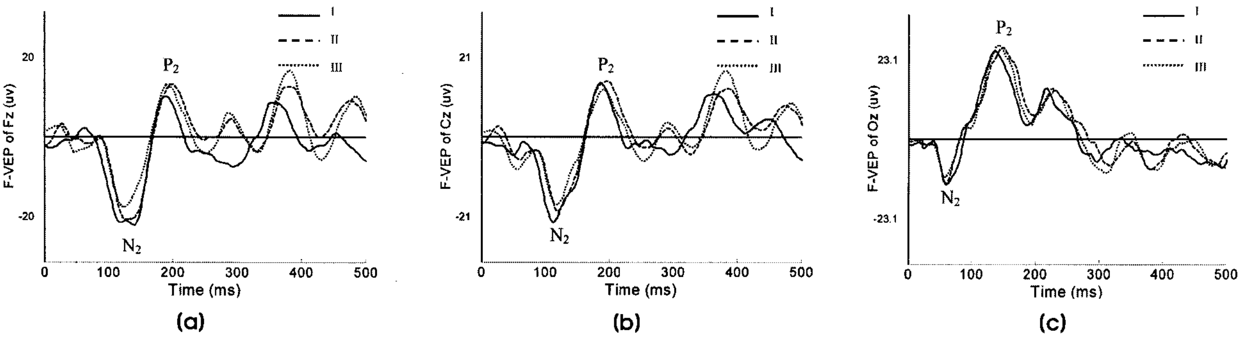

Fig. 8. The α-dependent F-VEPs of one meditator recorded on (a) Fz, (b) Cz, and (c) Oz.

of different sections. The p value is calculated by paired t-test (compared with selves in different phases) and t-test (compared to the other group in the same phase). Amplitudes of P1-N2 and N2-P2 on Cz and Fz increased significantly during meditation, yet, decreased during relaxation in the control group. On the other hand, N2-P2 amplitude on Fz decreased after meditation (experimental group) but increased after rest (control group). Apparently,the transit from one to another section caused F-VEP amplitudes on Cz and Fz to vary in opposite directions for both groups. We also observed significant differences between two groups in P1-N2 and N2-P2 amplitudes (Oz). P1-N2 amplitude (Oz) decreased during meditation but increased during rest. N2-P2 amplitude increased in the control group, but had little change in the experimental group. Contrary to the earlier peaks P1-N2 and N2-P2, N3-P3 amplitude (Oz) in the control group slightly decreased, whereas this peak amplitude increased in the experimental group.

Among all the F-VEP components, the most noticeable difference between two groups was the N2-P2 of Cz and Fz. Fig. 9 plots the variations of N2-P2 amplitudes at Cz and Fz. Each bar represents the percentage of F-VEP varying from section I to section II $\left(\frac{\mathrm{II}-\mathrm{I}}{\mathrm{I}}\times 100\%\right)$ for one subject (white: experimental subject, gray: control subject). Significant distinction is observed between two groups. Most meditation practitioners had their N2-P2 amplitudes increasing by an average rate of 20.1% (standard deviation among 11 subjects was 15.12%). Control subjects, on the contrary, exhibited a decreasing trend (average rate: -6.36%, standard deviation: 7.78%).

Ⅳ. CONCLUSION AND DISCUSSION

In this paper, we have reported an alternative strategy to investigate the effects of Zen-meditation on human brain. Alpha-dependent F-VEP analysis was suggested as a standardized and consistent scheme for investigating the event-related response dependency on oscillatory features of the meditation EEG. Without any access into the real system dynamics of the brain, scientific study requires manipulating

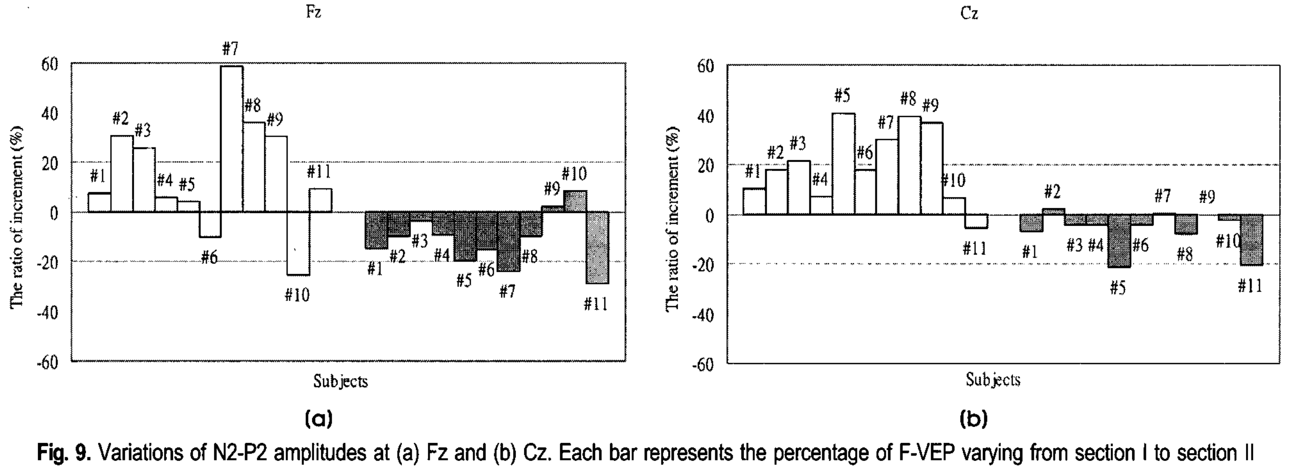

Fig. 9. Variations of N2-P2 amplitudes at (a) Fz and (b) Cz. Each bar represents the percentage of F-VEP varying from section I to section II $\left(\frac{\mathrm{II}-\mathrm{I}}{\mathrm{I}}\times 100\%\right)$ for each individual subject (white: experimental subject, gray: control subject).

the experiment under pre-specified conditions. Accordingly, alpha-dependent F-VEPs were collected under the consistent alpha-dominating background EEG that increased significantly during Zen meditation process. Based on the same scheme, the online α-detection algorithm could be modified for investigating the brain evoked response under given background EEG activity associated with other brain states, for example, theta- or beta-dominating background rhythms.

Our study has shown a great difference in the amplitudes of F-VEPs between the experimental and control group. Apparently, the meditation process modulates the amplitudes of F-VEPs under frontal α-rhythm emergence, especially components P1-N2 and N2-P2. These three peaks P1, N2 and P2, emerge respectively at about 80, 120 and 190 ms after photic stimulation. Moreover, such F-VEP amplitude variations for Zen-meditation practitioners were more consistent at the electrode locus Cz than at Fz. Since subjects mostly focused on the Zen Chakra (the third ventricle) during Zen meditation, we thus infer that meditation focusing changes the brain dynamics and the sensory responses to the external stimulus.

According to the literatures of visual function research, P1 component is generated from the major striate area, and N2 and P2 are generated from V4 which might be related to selective attention [30][34-35]. The increase of F-VEP amplitude indicates that Zen meditation, differing from normal relaxation, may cause some effects on primary visual cortex, central cortex, and frontal cortex. The study may assist in further understanding the intrinsic mechanism of such evidence as improving efficiency of the concept learning and integrating the brain function via Zen-meditation that has been reported.

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