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The Effect of Magnetic Field Direction on the EEG and PPG Obtained from Pulsed Magnetic Stimulus at Acupoint PC9

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Compared to acupuncture, the pulsed magnetic field (PMF) stimulus is a useful tool for treatment of many physical conditions and health maintenance due to its advantages as a noninvasive and nontoxic medical treatment. The purpose of this study was to investigate the effect of PMF stimulus direction at PC9 on the alpha activity of electroencephalogram (EEG) and vascular aging calculated from photoplethysmograph (PPG). It can be concluded that the direction of PMF stimulus affects the increase of alpha activity of EEG and PPG, indicating the vascular stiffness and the sclerosis level of blood vessels weakly relevant to the direction of PMF stimulus.

Keywords : pulsed magnetic field stimulus, electroencephalogram, alpha activity, photoplethysmograph, aging index

1. Introduction

Stimulation of the human body using pulsed electromagnetic fields (PMF) has the advantages of being comfortable and less painful, since the method conducts impulses toward the deep tissues with less stimulus intensity than acupuncture. The effects of pulsed and static electromagnetic fields on the microvascular blood system have been elucidated in many studies [1, 2]. We also reported the effect of a strong PMF in knuckles using photoplethysmograph (PPG) [3].

The autonomic nervous system (ANS) is the part of the peripheral nervous system that acts as a control system, functioning largely below the level of consciousness, and controlling visceral functions. Whereas most of its actions are involuntary, others, such as breathing, work in tandem with the conscious mind. Some papers reported that acupuncture can modulate ANS function. For example, Haker *et al.* demonstrated that acupuncture stimulation at Hegu point (LI4) was associated with a significant increase in the high-frequency (HF) component of heart-rate variability (HRV), reflecting parasympathetic activity of ANS [4]. Sakatani *et al.* evaluated the effect of acupuncture on ANS and frontal lobe activities, which played an important role in stress responses by modulating the ANS [5].

According to traditional Chinese medicine, appropriate acupuncture stimulation at specific acupoints could improve Shen disturbance, which manifests in patients presenting with symptoms of depression, mental health problems and emotional disorders [6, 7]. Changes in electroencephalogram (EEG) power and autonomic nerve activity during acupuncture stimulation were investigated in several papers [8]. The alpha-wave is between 8-13 Hz; increase in this frequency range will be especially effective for neurological disease patients who need mental relaxation. This is an important frequency range for treating Shen disturbance. Our previous study showed that application of PMF stimulus at some acupoints (PC9 and HT9) has effects on EEG alpha activity in the human brain, and affects cerebral function and the autonomic nerve system by measurable changes in EEG alpha activity [9].

In this study, two different shapes of coils - elliptic spiral and circular solenoid - were used to investigate whether the direction of PMF stimulus at acupoint PC9 would affect EEG alpha activity. Also, the volume of blood flow and vascular stiffness were measured using PPG in order to discern the effects of PMF stimulus direction at acupoint PC9. The elliptic spiral-shaped coil generates PMF perpendicular to PC9, and the circular solenoid coil generates PMF parallel to the finger. Therefore, our main purpose of this study is to show sedation and tonification effects which are exerted depending on

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the direction of PMF stimulus, through measurement of alpha EEG waves typically associated with a state of mental relaxation. The secondary purpose is to measure improvement of blood flow and vascular aging as an outcome of the direction of PMF stimulus by means of PPG.

2. Experimental Method

The effect of the direction of pMF stimulus on the EEG was investigated in 6 normal volunteer subjects (4 male, 2 female) ranging in age from 20-25 years, with consent obtained before the study. In order to be confident in the data from each subject, PPG signals in the middle finger were measured four times on four different days Since the EEG and PPG signals may vary both in power and frequency due to the physical movements and mental state of the subject, the subjects sat in a comfortable chair with eyes closed before the experiment for 10 min. It is most important to minimize any possible disturbance during the experiment. The subjects were stimulated using PMF generated from two different shapes of coils. The frequency of stimulation was 2 Hz. The maximum magnetic fields and pulse transition times of the two coil types - elliptic spiral and circular solenoid - were 0.47 T, 0.56 T and 0.102 ms, 0.074 ms, respectively. The digital EEG and PPG equipment used was the MP35 system (BIOPAC Systems, Inc., Santa Barbara, CA, USA) fixed at 200 Hz sampling rate with notch filter at the 60 Hz power line frequency. Electrodes for EEG measurement were placed on the parietal and occipital regions of the cerebral cortex to record alpha wave of greatest amplitude, and PPG sensor was attached to the distal phalanx of the middle finger. The EEG data were measured before, during and after PMF stimulus for 10 min. Frequency analysis was performed using fast Fourier transform to measure change in alpha power of EEG before and after PMF stimulus, indicating the autonomic nervous activity of central nervous system. To investigate the change in the blood flow in the peripheral vessel caused by PMF, the PPG signals were analyzed through second derivative PPG pulse (SDPPG) [3].

Fig. 1 shows: (a) the basic circuit of a PMF stimulator and schematic diagram of magnetic flux density distributions of (b) elliptic spiral and (c) circular solenoid coil. The elliptic spiral-shaped coil generates PMF perpendicular to acupoint PC9, and the circular solenoid shaped coil generates PMF parallel to the middle finger.

3. Results and Discussion

Figure 2 shows the schematic diagrams for (a) elliptic spiral and (b) circular solenoid coil and the simulation of magnetic field profiles by means of finite element method magnetics (FEM, version 2.0). Inserted graphs show the magnetic field intensities along the x-axis. Simulation results show that elliptic spiral coil produces a stimulation field concentrated at acupoint perpendicular to the end of finger, and circular solenoid coil generates a stimulation field along meridian line in the middle finger. Accordingly, stimulus field directions are confirmed by simulation results.

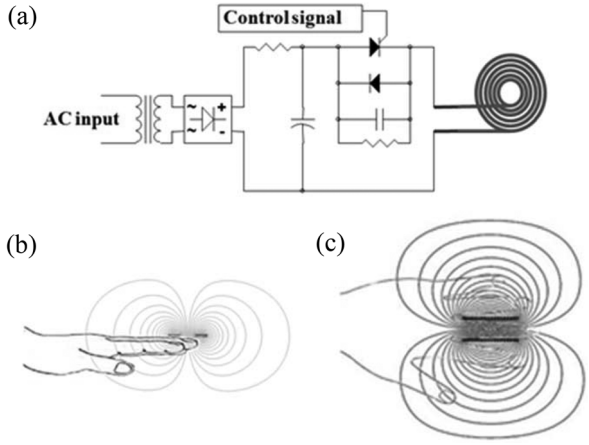

Fig. 1. (a) Basic circuit of a PMF stimulator and schematic diagram of magnetic flux density distributions of (b) elliptic spiral and (c) circular solenoid coil. The elliptic spiral shaped coil generates a PMF perpendicular to acupoint PC9 and the circular solenoid shaped coil generates a PMF parallel to the middle finger.

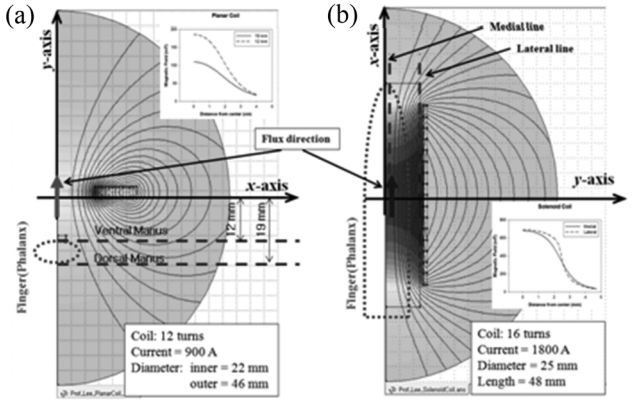

Fig. 2. Simulation of magnetic field profiles in the distance from center for (a) elliptic spiral and (b) circular solenoid coil by means of FEM 2.0. Inserted graphs show the magnetic field intensities along the x-axis. Simulation results show that elliptic spiral coil produces the stimulation field concentrated at acupoint perpendicular to the end of the finger, and the circular solenoid coil generates the stimulation field along the meridian line of the middle finger.

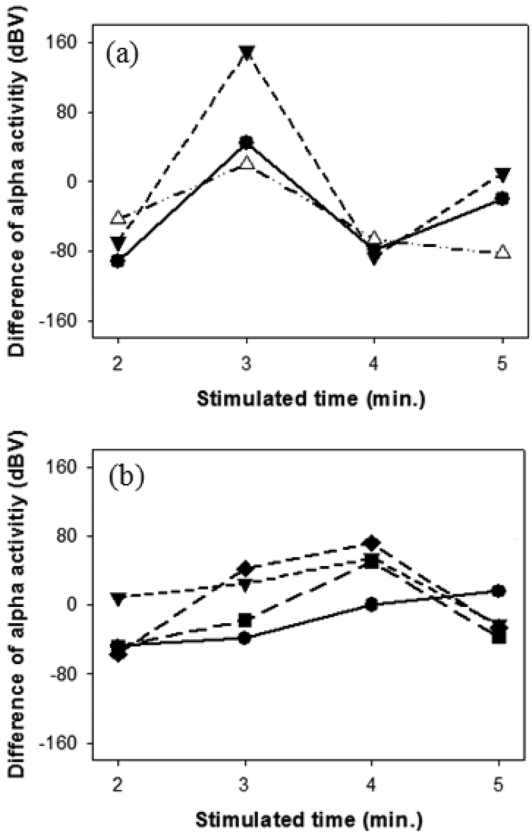

Fig. 3. Changes in alpha activity before and after stimulus with various PMF stimulus durations. The results presented alpha activity obtained from 4 selected subjects when PC9 was stimulated in the perpendicular direction (a) and parallel to the finger (b). It is shown in (a) that the increase in alpha activity occurred after a PMF stimulus of 3 min. However, alpha power is reduced after a PMF stimulus of 2, 4, and 5 min, but in (b) there is no increase in alpha power after a PMF stimulus of 3 min.

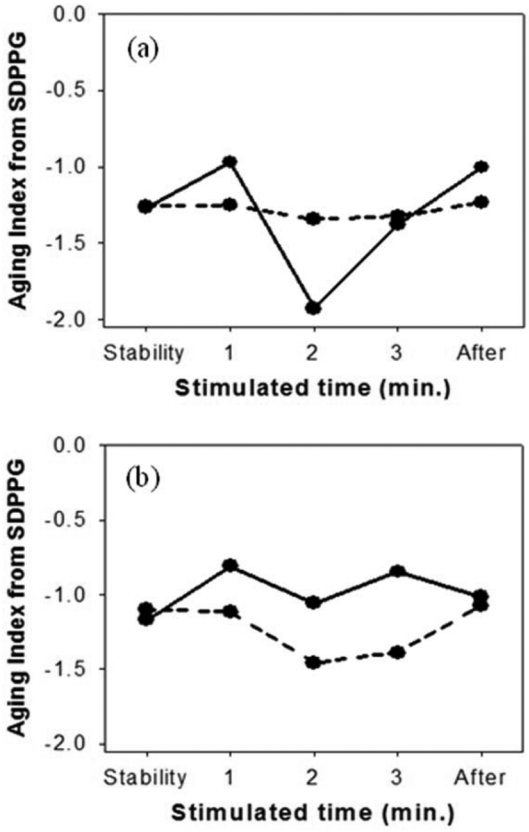

Fig. 4. Aging index values calculated from SDPPG by using (a) the elliptic spiral, and (b) the circular solenoid.

The changes in alpha activity before and after stimulus with PMF stimulus of various durations are shown in Fig. 3. The results present alpha activity obtained from 3 selected subjects when PC9 was stimulated with the (a) perpendicular direction and (b) parallel to the finger. It is shown in Fig. 3(a) that the increase in alpha activity occurred considerably after PMF stimulus of 3 min. However, alpha power was reduced after pMF stimulus of 2, 4, and 5 min. On the other hand, in Fig. 3(b), there are increases in alpha power after PMF stimulus of 4 min. This means that perpendicular direction of PMF at PC9 is directly to stimulate the acupoint, which causes the meridians to reopen and allows for a smooth flow of energy as compared to the parallel direction of PMF. Therefore in the circular solenoid shaped coil more exposure duration of PMF stimulus was required in order to increase alpha power, i.e. to induce mental relaxation. The change of cerebral nerve signal was observed depending on the stimulus direction at the acupoint using PMF, and this result means that it is applicable to the new noninvasive stimulus technique for specific acupoint. In this study, significant changes in 3 min. and 4 min. which correspond to perpendicular (acupoint) and parallel (meridian line) stimulus, respectively, were observed.

However, in our previous work, the effect of PMF stimulus on the improvement of vascular disorder and aging was reported. When PMF stimulus was applied to the broad area, including peripheral vascular system, for 3 min., there was confidential improvement of blood flow. Therefore, in this study, PPG signals were analyzed in order to evaluate the effect of stimulus direction - perpendicular to the specific acupoint PC9 and parallel to the meridian line - on the improvement of vascular disorder and aging. The stimulus duration showing significant change of EEG alpha activity in Figure 3 was also selected for PPG experiment.

Fig. 4 shows the aging index value calculated from SDPPG by using (a) the elliptic spiral, and (b) the circular solenoid. Contrary to EEG results obtained under PMF stimulus using two differently shaped coils, aging indices

calculated from SDPPG related to vascular aging were decreased at 2 min. in both coils. It is thought to be that that the improvement of vascular aging is weakly relevant to the direction of PMF stimulus.

For the PMF stimulus of focused area to the body, a clear difference was observed between the results of EEG and PPG. It is concluded that the change of EEG signal reflects the result of central nervous activity, while PPG signals are mainly affected by changes of ionic current in the blood vessel, rather than nervous activity.

4. Conclusion

We have investigated the effects on the direction of PMF stimulus using two different shaped coils, perpendicular and parallel to acupoint PC9 in the middle finger, respectively, by means of EEG and PPG. We found that the increase in EEG alpha activity occurred considerably after PMF stimulus of 3 min. for the elliptical spiral-shaped coil, and 4 min. for circular solenoid. The stimulus to meridian line - parallel to the middle finger - needed more exposure duration of PMF stimulus in order to increase alpha power, i.e., to obtain mental relaxation, than perpendicular direction. We also observed that PPG signals are not closely related to the stimulus direction. From these results, it might be concluded that PPG signals are mainly affected by change of ionic current in the blood vessel, and alteration in the EEG signal reflects the result of central nervous activity. Therefore, stimulus direction is important in the development of magnetic stimulation devices for medical applications, such as treating Shen disturbance and vascular diseases.

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