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# Effects of Cranial Electrotherapy Stimulation on Electrocephalogram

Background: Although cranial electrotherapy stimulation (CES) is reported to have positive effects on mental functions such as depression and sleep improvement, detailed studies regarding awakening, attention and concentration among brain waves reflecting brain activity are lacking.
Objective: To examine the effects of cranial electrotherapy stimulation (CES) on various electroencephalograms (EEGs) reflecting brain activities.
Design: Randomized controlled clinical trial (single blind)
Methods: This study selected 30 healthy adult women in their 20s who volunteered for this experiment. A total of 30 subjects were randomly assigned to three groups (Sham group, 0.5 Hz CES group, and 100 Hz CES group). EEGs were measured before and after the single CES, and the results were compared and analyzed.
Results: The relative theta, alpha, and gamma waves indicated no significant differences in the interaction effects between time and group. The relative fast alpha wave only showed significant differences in the interaction effects between time and group in P4. The relative slow beta wave only indicated statistically significant differences in the interaction effects between time and group in T3 and T4. The relative mid and fast beta waves showed statistically significant differences in the interaction effects between time and group in all areas.
Conclusions: These results suggest that a CES of 0.5 Hz awakens consciousness and has a positive influence on brain activity, while a CES of 100 Hz has a positive influence on thinking activity accompanying mental load during concentrating on one subject.

Key words: *Cranial electrotherapy stimulation, Electroencephalogram, Microcurrent*

**Jeongwoo Lee, Ph.D, Prof.[a], Hyejein Lee, BSc, PT[a], Woongsik Park, Ph.D, Prof.[a]**

[a]Kwangju Women's University, Gwangju, Republic of Korea

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Address for correspondence
Jeong Woo Lee, PT, Ph.D
Department of Physical Therapy, Kwangju Women's University, 201 Yeo-daegil, Gwangju, Korea
Tel: 82-62-950-3659
E-mail: jwlee@kwu.ac.kr

## INTRODUCTION

Cranial electrotherapy stimulation (CES) is the process of applying low level current to the head for therapeutic purposes [1]. In the USA, CES was called "electrosleep" during the 1960s and early 1970s, and it was accidentally found to reduce stress, as well as states of anxiety and depression [2]. For those patients whose positive results were reported after CES, they experienced better sleep, recall, and concentration, as well as a heightened state of well-being, and improved ability to learn after one or a series of CES treatment [3]. CES has been known by many different names, such as transcranial electrotherapy (TCET), transcranial stimulation (TCS), cranial stimulation (CS), neuroelectric therapy (NET), and electrosleep (ES) [4]. It is not fully clear at present why administering microcurrent stimulation across the head in CES reduces anxiety and depression. However, some experts would point to a possible reason that the alternating microcurrent may initially stimulate afferent branches of cranial nerves by earlobe electrodes [5].

CES is used for pain relief, and a study suggested that CES was very effective in managing chronic pain patients and increasing pain threshold indirectly by relieving anxiety and depression [6]. It was recently reported that CES activated the brain cells of the mentally retarded and helped improve their cognitive functions [7]. A pilot study on EEG related to the CES reported that the delta and gamma waves were reduced, the alpha wave was increased 20 minutes after CES, and anxiety was reduced [1]. However, experimental studies related to various EEGs reflecting brain activities are deemed necessary. This is because very few CES studies have been reported regarding concentration, attention, and so on which are important factors in task performance. Therefore, this study examined the effects of CES on various EEGs reflecting brain activities.

## SUBJECTS AND METHODS

### Subjects

The subjects of this study were 30 normal female in their 20s who attended Kwangju Women's University. The general characteristics are listed in Table 1. The subjects gave their written informed consent if they agreed to participate. This study was approved by the ethics committee of Kwangju Women's University (1041485-201710-HR_001-30). All the participants signed the informed consent form before participating in the study. The subjects were randomly divided into three groups (the sham, .5Hz, and 100Hz groups). This study was randomized controlled clinical trial (single blind). There were no statistically significant in homogeneity of general characteristics between groups (Table 1). The research subjects included those who had no neuromuscular or musculoskeletal diseases, who did not perform regular exercises in the last six months, and who did not take any medicine that might have affected the experiment results.

### Cranial Electrotherapy Stimulation

The subjects took a rest at a sedentary position for five minutes before the experiment. All CES groups were applied with microcurrent at a sedentary position by using Endomed 482 (Enraf-Nonious, Netherlands) at an alternating mode of 10 ㎂ intensity for 20 minutes. The CES frequency is set to .5Hz and 100Hz CES by referring to the previous study [8]. The sham group was applied in the same way as the CES groups, but not actual electrical stimulation. A rectangular shaped disposable adhesive electrode (2223H, Hurev, Korea; 1 cm x 1 cm) was applied to both earlobes of the subjects after cleaning with alcohol swab.

### EEG Measurement

The indoor temperature in measuring EEG should be kept at 24-26℃ and humidity at 60-65%. The subjects were instructed not to make unnecessary movements (e.g., blinking, yawning, or frowning) or wear any metal or electronic devices (e.g., mobile phone), and the noises were controlled. The participant's measurement postures were comfortably seated in a chair, with their arms resting on their legs, with their head facing forward. EEG LXE5208 (Laxtha, Korea), sampling frequency of 256 Hz, gain value of 1250 ㎶, and band pass filter of 4~50 ㎐ were set. The oil and dead skin cells of the scalp, to which the electrode is attached, should be cleaned with alcohol swab before the experiment. Neuro-MEP-4 (Neurosoft Ltd., Russia) was used to measure the scalp resistance at less than 5㏀ of scalp resistance.
The electrode for EEG measurement was attached to F3, F4, T3, T4, P3, and P4 by using the international 10-20 system, reference electrode to the right mastoid, and ground electrode to left mastoid. The subjects took a rest at a sedentary position for five minutes before the experiment. They were instructed to see the mark at 87 cm height considering the average sitting height of adult women. EEGs were measured once before and after CES when the subjects saw the mark for 2 minutes and 30 seconds.

The EEG frequency was set at fast alpha wave (11~12.99 Hz), slow beta wave (12~14.99 Hz), mid beta wave (15~19.99 Hz), fast beta wave (20~29.99 Hz) The EEG frequency was set at fast alpha wave (11~12.99 Hz), slow beta wave (12~14.99 Hz), mid

**Table 1.** Characteristics of subjects

| Group | Sham (Mean±SD) | .5Hz CES (Mean±SD) | 100Hz CES (Mean±SD) | p |
|---|---|---|---|---|
| Age (yr) | 20.6±1.1 | 21.1±1.1 | 21.9±0.3 | .282 |
| Height (cm) | 160.9±4.0 | 161.3±4.0 | 164.3±4.6 | .067 |
| Weight (kg) | 51.4±3.7 | 53.1±5.3 | 53.6±5.3 | .130 |

CES: cranial electrotherapy stimulation

beta wave (15~19.99 Hz), fast beta wave (20~29.99 Hz) and they were analyzed with relative frequency. All EEGs were calculated with relative frequency as follows.

Relative Frequency = Each Frequency / Total Frequency

*. Total frequency= frequency of EEG from theta wave to gamma wave (4~50 Hz)

### Statistical analysis

Statistical analysis was performed using the Windows SPSS 19.0 program. Two-way repeated measures ANOVA was used to analyze the changes that occurred in the three groups according to the treatment duration. The significance level was set to $\alpha$=.05.

## RESULTS

### Changes of the Relative Fast Alpha Wave

The analysis result of the relative fast alpha wave changes indicated that there were statistically significant interaction effects between time and group only in P4. Therefore, the patterns of change between groups were found to be different in P4 (Table 2)(p<.05).

**Table 2.** Changes of relative fast alpha wave

| Area | Group | Pre | Post | p | | |
|---|---|---|---|---|---|---|
| | | | | Time | Time x Group | Group |
| F3 | Sham | .06±.01 | .08±.03 | .026* | .756 | .763 |
| | .5Hz | .06±.01 | .07±.02 | | | |
| | 100Hz | .07±.02 | .07±.02 | | | |
| F4 | Sham | .06±.01 | .07±.02 | .397 | .792 | .602 |
| | .5Hz | .06±.02 | .06±.03 | | | |
| | 100Hz | .07±.02 | .07±.02 | | | |
| T3 | Sham | .08±.02 | .08±.02 | .015* | .715 | .922 |
| | .5Hz | .07±.01 | .09±.02 | | | |
| | 100Hz | .08±.01 | .09±.01 | | | |
| T4 | Sham | .07±.01 | .07±.02 | .154 | .542 | .675 |
| | .5Hz | .07±.01 | .07±.02 | | | |
| | 100Hz | .07±.01 | .08±.02 | | | |
| P3 | Sham | .09±.03 | .09±.03 | .656 | .345 | .461 |
| | .5Hz | .10±.02 | .11±.03 | | | |
| | 100Hz | .11±.04 | .10±.39 | | | |
| P4 | Sham | .09±.02 | .08±.02 | .804 | .046* | .278 |
| | .5Hz | .09±.02 | .11±.04 | | | |
| | 100Hz | .11±.04 | .11±.03 | | | |

Mean±SD
*p<.05
The relative fast alpha wave only showed significant interaction effects between time and group in P4. The main effects time only showed significant differences in F3 and T3 (p<.05).

## Changes of the Relative Slow Beta Wave

The analysis results of the relative slow beta wave changes showed that there were statistically significant interaction effects between time and group only in T3 and T4. Therefore, the patterns of change between groups were only found to be different in T3 and T4 (Table 3)($p < .05$).

**Table 3.** Changes of relative slow beta wave

| Area | Group | Pre | Post | p | | |
|---|---|---|---|---|---|---|
| | | | | Time | Time x Group | Group |
| F3 | Sham | .07±.01 | .08±.03 | .067 | .641 | .878 |
| | .5Hz | .08±.02 | .09±.03 | | | |
| | 100Hz | .07±.02 | .09±.07 | | | |
| F4 | Sham | .07±.01 | .08±.03 | .213 | .400 | .745 |
| | .5Hz | .09±.03 | .09±.03 | | | |
| | 100Hz | .07±.02 | .09±.07 | | | |
| T3 | Sham | .10±.02 | .01±.02 | .007* | .019* | .556 |
| | .5Hz | .10±.02 | .11±.03 | | | |
| | 100Hz | .09±.02 | .14±.06 | | | |
| T4 | Sham | .11±.03 | .10±.02 | .098 | .047* | .183 |
| | .5Hz | .12±.03 | .13±.03 | | | |
| | 100Hz | .08±.02 | .12±.06 | | | |
| P3 | Sham | .09±.03 | .09±.03 | .467 | .902 | .033* |
| | .5Hz | .11±.03 | .11±.03 | | | |
| | 100Hz | .07±.03 | .07±.03 | | | |
| P4 | Sham | .09±.02 | .09±.04 | .406 | .964 | .017* |
| | .5Hz | .11±.02 | .11±.03 | | | |
| | 100Hz | .06±.03 | .07±.03 | | | |

Mean±SD
*$p < .05$
The relative slow beta wave only showed significant interaction effects between time and group in T3 and T4 ($p < 0.05$). The main effects time showed significant differences in T3 ($p < .05$). The main effects group showed significant differences in P3 and P4 ($p < .05$).

### Changes of the Relative Mid Beta Wave

The analysis results of the relative mid beta wave changes showed that there were statistically significant interaction effects between time and group in all areas. Therefore, the patterns of change between groups were found to be different in all areas (Table 4)($p<.05$).

**Table 4.** Changes of relative mid beta wave

| Area | Group | Pre | Post | p | | |
|---|---|---|---|---|---|---|
| | | | | Time | Time x Group | Group |
| F3 | Sham | .11±.03 | .10±.03 | .007* | .001* | .002* |
| | .5Hz | .12±.04 | .11±.05 | | | |
| | 100Hz | .08±.03 | 8.12±8.76 | | | |
| F4 | Sham | .10±.03 | .10±.05 | .012* | .003* | .003* |
| | .5Hz | .13±.05 | .14±.13 | | | |
| | 100Hz | .08±.04 | 8.55±9.86 | | | |
| T3 | Sham | .13±.03 | .12±.04 | .001* | .000* | .000* |
| | .5Hz | .18±.08 | .17±.08 | | | |
| | 100Hz | .12±.03 | 3.66±2.93 | | | |
| T4 | Sham | .16±.06 | .15±.08 | .002* | .000* | .000* |
| | .5Hz | .19±.08 | .20±.09 | | | |
| | 100Hz | .12±.04 | 4.48±3.88 | | | |
| P3 | Sham | .19±.03 | .08±.02 | .002* | .000* | .000* |
| | .5Hz | .15±.04 | .13±.06 | | | |
| | 100Hz | .07±.03 | 10.47±9.76 | | | |
| P4 | Sham | .09±.02 | .09±.02 | .003* | .000* | .000* |
| | .5Hz | .16±.05 | .13±.06 | | | |
| | 100Hz | .08±.04 | 10.48±10.16 | | | |

Mean±SD
*$p<.05$
The relative mid beta wave showed significant interaction effects between time and group in all areas ($p<.05$).

### Changes of the Relative Fast Beta Wave

The analysis results of the relative fast beta wave changes showed that there were statistically significant interaction effects between time and group in all areas. Therefore, the patterns of change between groups were found to be different in all areas (Table 5)($p<.05$).

**Table 5.** Changes of the relative fast beta wave

| Area | Group | Pre | Post | p | | |
|---|---|---|---|---|---|---|
| | | | | Time | Time x Group | Group |
| F3 | Sham | 2.36±1.38 | 2.60±.98 | .022* | .004* | .008* |
| | .5Hz | 2.00±1.11 | 1.98±1.34 | | | |
| | 100Hz | 8.47±7.59 | 2.67±1.28 | | | |
| F4 | Sham | 2.55±1.40 | 3.04±1.64 | .044* | .004* | .027* |
| | .5Hz | 1.79±1.22 | 2.15±1.50 | | | |
| | 100Hz | 9.10±9.23 | 2.89±1.97 | | | |
| T3 | Sham | 2.11±.94 | 2.33±1.31 | .049* | .003* | .035* |
| | .5Hz | 1.47±.92 | 1.61±1.02 | | | |
| | 100Hz | 4.02±2.56 | 1.79±.57 | | | |
| T4 | Sham | 1.65±1.04 | 1.95±1.47 | .047* | .004* | .003* |
| | .5Hz | 1.13±.76 | 1.20±.89 | | | |
| | 100Hz | 4.33±2.85 | 1.78±.72 | | | |
| P3 | Sham | 4.88±3.72 | 5.89±5.10 | .163 | .003* | .072 |
| | .5Hz | 2.01±.86 | 3.09±2.63 | | | |
| | 100Hz | 10.26±9.72 | 4.66±3.67 | | | |
| P4 | Sham | 4.52±3.36 | 4.97±3.99 | .205 | .030* | .097 |
| | .5Hz | 1.93±1.10 | 2.96±2.72 | | | |
| | 100Hz | 10.04±11.83 | 4.40±3.08 | | | |

Mean±SD
*p<.05
The relative fast beta wave showed significant interaction effects between time and group in all areas (p<.05).

## DISCUSSION

This study analyzed EEGs that reflect brain activity, such as attention, concentration, and stress state, through more detailed EEGs analysis than previous studies. It was found that the relative fast alpha wave only increased in the parietal lobe area (P4) of the .5 HZ CES group. Alpha wave (8~12 Hz) is related to rest and relaxation state [9]. The alpha wave was found when the brain and muscles were relaxed, and the body and mind were harmonized [10]. Relative fast alpha power spectrum (11~13 Hz) is related to comfort and attention [11]. Alpha waves between 9 to 11 Hz occur when a person meditates or is in a clear state of mind [12]. In the results of this study, it has influence on the fast alpha wave. Therefore, the result of this study suggest that the .5 Hz CES might be helpful for a person to meditate or have a clear state of mind.

It was found that 100 Hz CES only increased the relative slow beta wave in temporal lobe. Also, 100 Hz CES increased the mid beta wave and reduced the relative fast beta wave in all areas of the lobe. Sensory motor rhythm (SMR; 12~15 Hz) wave is related to attention state, mid beta wave (16~20 Hz) is related to concentration state, and high beta wave (21~30 Hz) is related to tension, excitement, and stress state [10]. The neurofeedback training of the SMR (12–15 Hz) and 15–18 Hz beta wave improved the general attention (SMR) and arousal (15–18 Hz beta wave) [13]. In addition, the neurofeedback training of 12–15 Hz and 15–18 Hz beta waves increased in

P300 event-related brain potential amplitudes in an auditory oddball task [14]. Neurofeedback for inhibiting 4-7 Hz (theta wave) and increasing 15-21 Hz (mid beta wave) over sensory motor and speech area have improved in speech fluency, word finding, balance and coordination, attention, and concentration [15]. Therefore, this study was found that the 100 Hz CES might be helpful in thinking activities that require mental load as attention and concentration state and in reducing emotional tension, anxiety, and excitement.

Areas that related to remote semantic memory are the supramarginal and inferior frontal cortices bilaterally, the left insular cortex, and inferior temporal gyrus [16]. These areas have been activated in studies using visual imagery of objects or famous faces [17-18]. It has not yet been explain clearly why the frequency of CES are effective on certain EEG. Tanscranial alternating current simulation (tACS) is believed to mainly entrain with or synchronize neuronal networks, thus inducing changes in ongoing oscillatory brain activity [19]. Therefore, although stimulation methods are different, it is thought that CES may also be affected by the frequency of stimulation. The limitation of this study is that the subjects were normal adult women. Therefore, it has limitation to generalize the results of research to various cases with anxiety, depression, and stress.

## CONCLUSION

This study examined the effects of CES on various EEGs reflecting brain activities. These results suggest that the .5 Hz CES has a positive influence on brain activity for external information processing such as cognitive activity, while the 100 Hz CES has a positive influence on thinking activity accompanying mental load. The results of these studies might be used as a basic data source that can assist in treating the body's function through increased cognitive activity or mental load reduction depending on the stimulation frequency of CES.

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