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RESEARCH ARTICLE

Electric Field Exposure Improves Subjective Symptoms Related to Sleeplessness in College Students: A Pilot Study of Electric Field Therapy for Sleep Disorder

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Abstract: ***Background*:** Sleep disorder is a common health problem in modern days. Establishment of safe, non-invasive, convenient and effective treatment is anticipated in the field of complementary and alternative medicine.

***Objective*:** We designed a protocol for a randomized controlled trial to investigate the effect of Electric Field (EF) exposure on sleep disorder.

***Methods*:** Nineteen college students with sleep disorder, defined as a score of 8 or higher on the Pitzburg Sleep Quality Index, were divided into two groups; EF intervention and sham treatment. EF exposure (50-Hz, 18 kV) was performed for 30 minutes a day for five consecutive days. Subjective parameters were obtained by an OSA sleep inventory MA version consisting of five factors, and objective parameters were measured using a sleep-scan.

***Results*:** Significant improvement in scores of three factors (sleepiness on rising, refreshing and sleep length) was observed after 5 days of EF exposure intervention, as compared to both before intervention and after 5 days of sham treatment. Moreover, improvement ratios for these three factors were significantly higher in the EF group than in the sham treatment group. Analysis of the sleep-scan demonstrated a high improvement ratio for duration of nocturnal awakening in the EF group.

***Conclusion*:** The beneficial effect of electric field therapy on sleep disorder in college students is considered to be beyond a placebo effect. This study raises the therapeutic possibility of electric field exposure.

Keywords: Complementary and alternative medicine, electric field therapy, nocturnal awakening, OSA sleep inventory MA version, PSQI (Pitzburg Sleep Quality Index), sleep disorder, sleep-scan.

1. INTRODUCTION

Recently, there has been a focus on a variety of complementary and alternative medicine in the field of health care [1, 2]. Among various diseases, insomnia or sleep disturbance is a major target of complementary treatment, because sleep disorder

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is still one of the most common and ordinary health problems to be solved in various populations and generations all over the world, and conventional therapy is limited by the not few adverse events of sleeping medication. Safe and non-invasive treatment is actively being investigated in various fields of alternative and complementary medicine, such as acupuncture and aromatherapy, to name a few. Under such situations, in this study we documented the safety and convenience of a device that exposes subjects to an electric field, and clinically investigated the therapeutic potential of electric field therapy for sleep disorder with the aim of establishing non-invasive complementary treatment.

High-voltage electric field exposure has been widely used in Japan to improve health conditions since the development and approval for human use of a therapeutic device that exposes subjects to an electric field as a manufacturing apparatus by the Ministry of Health, Labour and Welfare in Japan [3, 4]. Although the influence of electric field exposure in humans is still poorly understood, a few recent reports have scientifically clarified its biological effect on metabolic regulation and expression of various substances in the living body [5-8]. Among them, it has already been reported that electric field exposure has an effect on the expression of some molecules related to stress and pain in clinical studies or basic studies using animal experiments [5, 8]. Thus, a beneficial clinical effect of electric field therapy for alleviation of sleep deprivation, shoulder stiffness, chronic pain and headache has been expected. However, as no high-quality clinical study investigating the improvement of these symptoms has been reported until now, the expected clinical effect of electric field therapy is still controversial. Electric field therapy is viewed with suspicion due to the lack of well-designed randomized, blinded, placebo-controlled trials employing a large number of subjects. Accurate elucidation of its efficacy is important for not only patients with sleep disorder, but also practitioners.

In the present study, we designed a protocol for a randomized, single-blinded, placebo-controlled trial employing college students to investigate the effect of electric field exposure on sleep disorder. Although the number of participants in the present study was small and limited to young adults, the study was strictly performed in a blinded manner and can be positioned as the first pilot study to investigate the effect of electric field therapy on sleep disorder. In this study, we evaluated the effect mainly by subjective parameters using OSA sleep inventory MA version, which was established as a scale of sleep disorder [9] and is popularly used in Japan. Also, objective parameters were recorded from a sleep-scan in the sleeping period. Here, the present study demonstrated improvement of subjective symptoms related to sleeplessness by exposure to an electric field, suggesting the possibility of electric field therapy as a safe and non-invasive option for sleep disorder, in addition to other standard interventions such as psychological and pharmacological intervention.

2. MATERIALS AND METHODS

2.1. Electric Field Exposure

The system that exposes subjects to an electric field was previously reported [3-7]. The system used in this study was a chair-type, equipped with a transformer and two insulator-covered electrodes. One electrode was placed on a floor plate on which the subject's feet were located, and the other was placed above the subject's head. These two electrodes build up an electric field around a subject who sits on this chair-type apparatus (Healthtron PRO-18T, Hakuju Institute for Health Science Co., Ltd., Tokyo, Japan). The electric field generated by Healthtron PRO-18T was uniformly created by transforming a 50-Hz alternating current at 18 kV. Healthtron PRO-18T was approved for human use by the Japanese government in 1963.

2.2. Subjects and Study Design of Intervention Trial

The present study was performed using a protocol for a randomized, single-blinded, sham-controlled trial. The subjects were 19 college students with no serious disease. We selected subjects with sleep disorder defined as a score of 8 or higher on the Pitzburg Sleep Quality Index (PSQI) [10]. Inclusion criteria were as follows; 1) over 18 and under 25 years old, 2) score of 8 or higher on the PSQI, 3) not receiving psychoactive or sleeping drugs, 4) no problem with communication or intelligence, and 5) provided signed written informed consent. Exclusion criteria were as follows;

1) diagnosis of depression, anxiety, schizophrenia or other severe mental disorder, 2) diagnosis of other sleep disorder such as obstructive sleep apnea or restless legs syndrome, 3) receiving other insomnia treatment in the past month, and 4) alcohol and/or other drug abuse or dependence. Baseline characteristics of the study subjects are shown in Table **1**. The subjects were randomly divided into two groups by an envelope method; subjects exposed to an electric field (EF group, n=9) and subjects not exposed to an electric field (sham treatment) as a control (C group, n=10). This study was performed in a blinded manner. Subjects in C group sat on the same chair-type apparatus without electricity turned on. As electric field exposure does not cause any symptoms, none of the subjects could distinguish chairs with energization from those without energization. Subjects in EF group received electric field exposure for 30 minutes a day for 5 days by sitting on the Healthtron PRO-18T. Subjects in C group, who were not exposed to an electric field by sham treatment, sat on the same apparatus without energization for 30 minutes a day on the same days.

2.3. Assessment Parameters

Subjective parameters related to sleeplessness were obtained by OSA sleep inventory MA version as sleep diaries. OSA sleep inventory MA version was developed and is popularly used in Japan to evaluate sleep quality [9]. This questionnaire consists of 16 items, each of which is graded as four levels, from 1 to 4, as a score. Sleep disorder assessed by this questionnaire is classified into five factors (sleepiness on rising, initiation and maintenance of sleep, dreaming, refreshing and sleep length), and the score of each factor is expressed as the total score of the items belonging to each factor (Table **2**). Standardization of OSA sleep inventory MA version has been adequately performed, and both reliability and reproducibility are high [9]. Besides subjective parameters, objective parameters were measured by attachment of a sleep-scan apparatus (Sleep-scan SL-503, Tanita Inc., Tokyo, Japan).

Sleep diaries and records from the sleep-scan were collected for 5 days before intervention as baseline, 5 days during intervention and 2 days after intervention. In both C group and EF group, parameters on day 5 after the start of intervention were statistically compared to the mean values of parameters during 5 days before intervention. Also, the improvement ratio, which is the ratio of the number of subjects who show improvement by the intervention to all subjects, for each parameter was analyzed in both groups by χ^2 test in cross-tabulation tables.

Table 1. Baseline clinical characteristics of study subjects.

Characteristics	C Group	EF Group	*P*
Number of subjects	10	9	
Age (years)	21.0±1.4	20.6±0.8	0.60
Sex (M/F)	4/6	6/3	0.25
PSQI (Pitzburg Sleep Quality Index)	10.3±1.1	10.3±2.5	0.50
OSA sleep inventory MA version			
Factor I (Sleepiness on rising)	10.4±4.6	12.4±4.0	0.32
Factor II (Initiation and maintenance of sleep)	12.9±5.1	17.0±3.8	0.07
Factor III (Dreaming)	19.2±9.0	19.6±6.3	0.90
Factor IV (Refreshing)	10.5±4.2	14.0±3.3	0.06
Factor V (Sleep length)	17.7±5.2	14.3±6.3	0.22
Sleep scan			
Total sleep time (s)	22935±3483	21420±3252	0.34
Duration of nocturnal awakening (s)	674±280	525±325	0.30
Duration of deep sleep time (s)	3833±805	3741±916	0.82

Values are expressed as mean±SD. P values were determined by Student's t test.

2.4. Ethics Statement

The study protocol was approved by the Ethics Committee for Clinical Investigation of Morinomiya University of Medical Sciences (Permit Number: 2015-33). The study was performed in compliance with these institutional guidelines. All of the participants gave written informed consent before entering the study, which was conducted in accordance with the Declaration of Helsinki.

2.5. Statistical Analysis

All numerical values are expressed as mean ± SEM. Data sets were analyzed by paired *t* test or unpaired Student's *t* test in the figures, and χ^2 test in cross-tabulation tables. Differences with $P < 0.05$ were considered statistically significant.

3. RESULTS

3.1. Baseline Clinical Characteristics of Subjects

Table **1** presents the baseline clinical characteristics of the participants in this study. PSQI (Pitzburg Sleep Quality Index) score of each subject was 8 or higher, indicating that all subjects had sleep disorder. There was no significant difference in age, sex, PSQI score and scores of each factor of OSA sleep inventory MA version between C group and EF group (Table **1**). Also, no significant difference between C group and EF group was observed in total sleep duration, duration of nocturnal awakening and duration of deep sleep, assessed by sleep-scan, as shown in Table **1**.

3.2. Effects of Electric Field Exposure on Subjective Symptoms in Subjects with Sleep Disorder

First, to evaluate the effect of electric field exposure on sleep disorder, we assessed scores of OSA sleep inventory MA version consisting of five factors of subjective symptoms; sleepiness on rising, initiation and maintenance of sleep, dreaming, refreshing and sleep length. As shown in Fig. (**1**), in EF group, scores of Factor I (sleepiness on rising), Factor IV (refreshing) and Factor V (sleep length) were significantly increased on day 5 of concecutive intervention of electric field exposure of 30 minutes a day as compared to before intervention (pre), while no significant change in scores of these factors was observed in C group. In addition, the raised scores of these three factors tended to be cancelled on day 2 of intervention of electric field exposure. Moreover, scores of Factor I, IV and V on day 5 in EF group were significantly higher than those in C group (Fig. **1**). Also, scores of these three factors increased day by day (Fig. **2**), suggesting an accumulative effect of electric field exposure and the importance of consecutive use. Although scores of both Factor I and Factor IV decreased at day 1, the reduction is not statistically significant.

Moreover, we compared the improvement ratio for each factor in C group to that in EF group by χ^2 test in cross-tabulation tables. Improvement ratio was defined as the ratio of the number of subjects in whom improvement was observed to all subjects, for each parameter. Of importance, improvement ratios for Factor I, IV and V were significantly higher than those in C group, as shown in Table **3**. These data obtained from OSA sleep inventory MA version demonstrated that 30 minutes of electric field exposure on five consecutive days improved subjective symptoms of sleep disorder and improved the subjective quality of sleep.

3.3. Analysis by Sleep-scan

We further assessed objective parameters by attachment of a sleep-scan. As shown in Fig. (**3**), total sleep time, duration of nocturnal awakening and duration of deep sleep time were not significantly changed by exposure to an electric field. Also, there was no significant difference in these parameters between C group and EF group. However, the improvement ratio for duration of nocturnal awakening in EF group (89%) was high as compared to that in C group (50%) (P=0.07), although no significant difference was observed (Table **4**).

4. DISCUSSION

Sleep disorder, which is mainly expressed as self-reported poor sleep quality, is exceedingly common and pervasive in various generations and populations in most countries [11, 12]. Fatigue, daytime sleepiness, mood disturbance, decreased performance, and cognitive impairment induced by poor sleep [13-15] can affect quality of life negatively [16, 17]. Moreover, there is a relationship between sleep disorders and morbidity rates of various diseases such as hypertension [18], diabetes

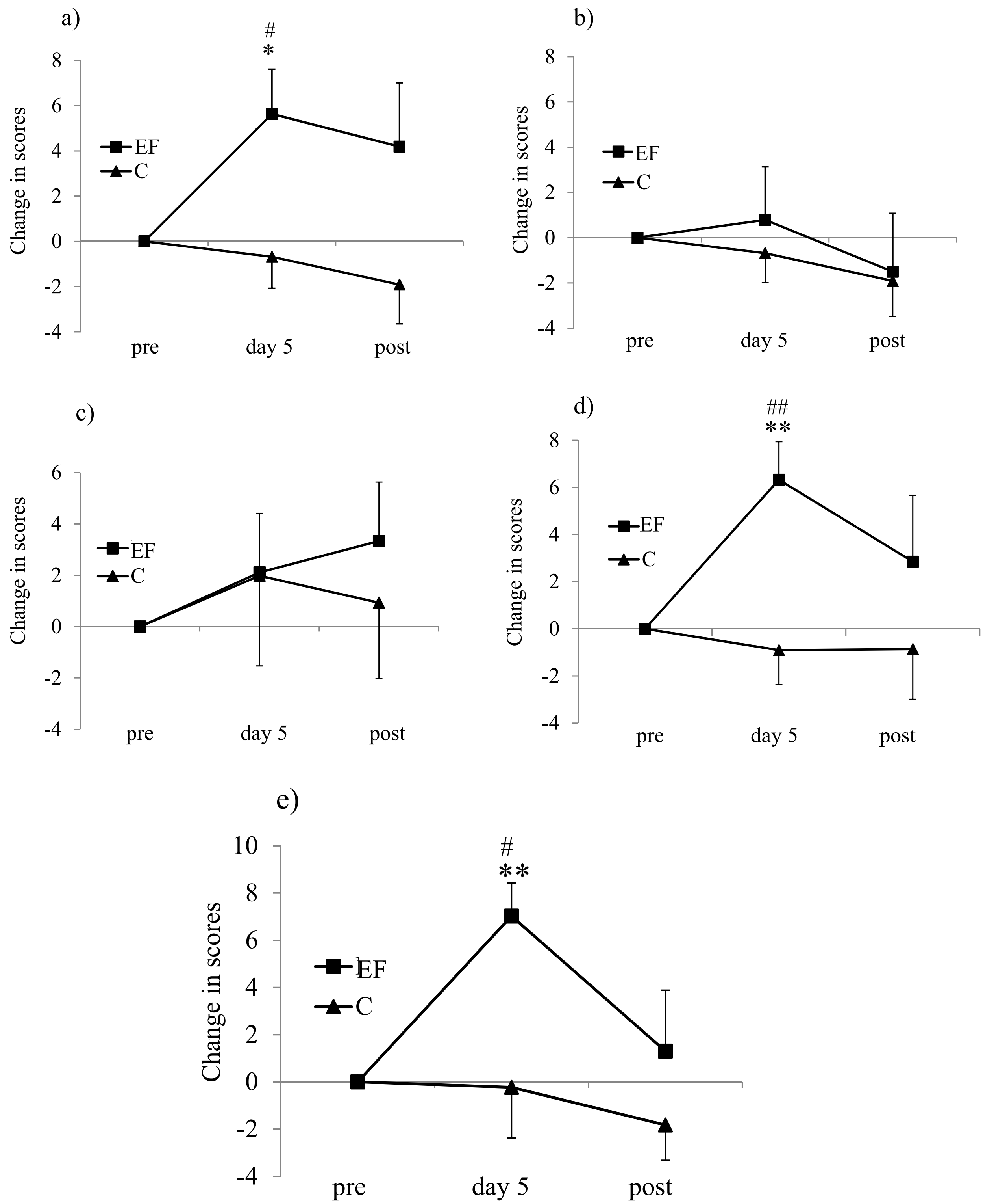

Fig. (1). Effect of electric field exposure on subjective symptoms assessed by change in each score of OSA sleep inventory MA version. **a**) Change in score of Factor I (sleepiness on rising), **b**) Change in score of Factor II (initiation and maintenance of sleep), **c**) Change in score of Factor III (dreaming), **d**) Change in score of Factor IV (refreshing), **e**) Change in score of Factor V (sleep length), EF: Group with EF intervention (n = 9), C: Group with sham treatment (n = 10), Pre: before intervention, Post: at 2 days after completion of intervention. Values are expressed as mean ± SEM. *P<0.05 *vs*. Pre, **P < 0.01 *vs*. Pre, # P<0.05 *vs*. C group, ## P<0.01 *vs*. C group.

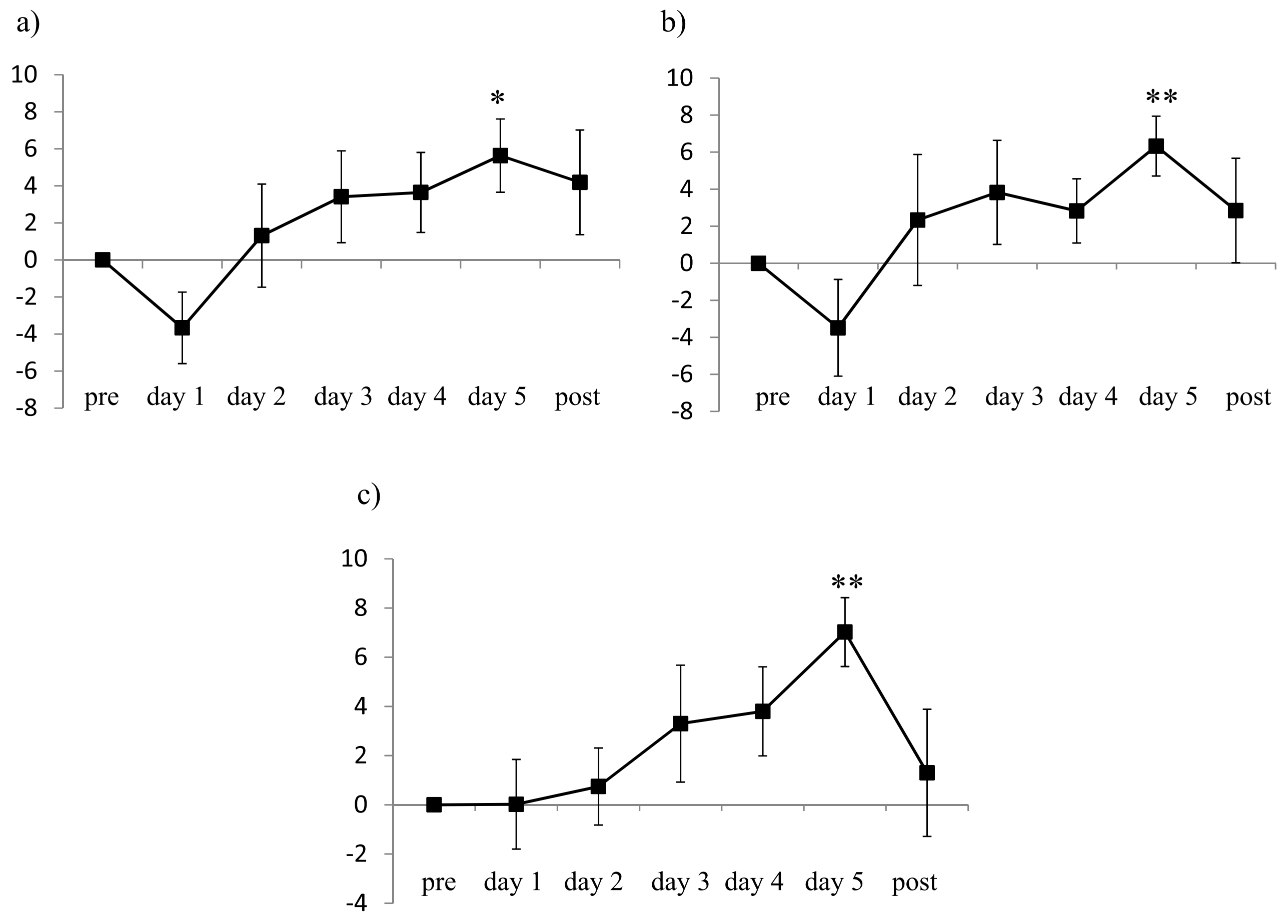

Fig. (2). Transition of scores in EF group. **a**) Change in score of Factor I (sleepiness on rising), **b**) Change in score of Factor IV (refreshing), **c**) Change in score of Factor V (sleep length), Pre: before intervention, Post: at 2 days after completion of intervention. Values are expressed as mean ± SEM. *P<0.05 *vs*. Pre, **P < 0.01 *vs*. Pre.

Table 2. Sixteen items and five factors of OSA sleep inventory MA version.

1. Tiredness	9. Nightmares
2. Concentration	10. Easy to fall asleep
3. Deep sleep	11. Unpleasant feeling
4. Comfort	12. Frequent dreaming
5. Fatigue	13. Frequent nocturnal awakening
6. Appetite	14. Able to answer questions quickly
7. Drowsiness till falling asleep	15. Long sleep time
8. Feeling clear headed	16. Light sleep

Score of Factor I (sleepiness on rising) is total of No. 2, 4, 8 and 14.

Score of Factor II (initiation and maintenance of sleep) is total of No. 3, 7, 10, 13 and 16.

Score of Factor III (dreaming) is total of No. 9 and 12.

Score of Factor IV (refreshing) is total of No. 1, 5, and 11.

Score of Factor V (sleep length) is total of No. 6 and 15.

Table 3. Improvement ratio for each parameter of OSA sleep inventory MA version.

Factors	Group	Improvement (+) Number of Subjects	Improvement (-) Number of Subjects	Improvement Ratio	*P*
Factor I	EF	8	1	89%	
	C	4	6	40	0.03
Factor II	EF	6	3	67%	
	C	4	6	40%	0.25
Factor III	EF	4	5	44%	
	C	6	4	60%	0.50
Factor IV	EF	8	1	89%	
	C	4	6	40	0.03
Factor V	EF	9	0	100%	
	C	5	5	50%	0.01

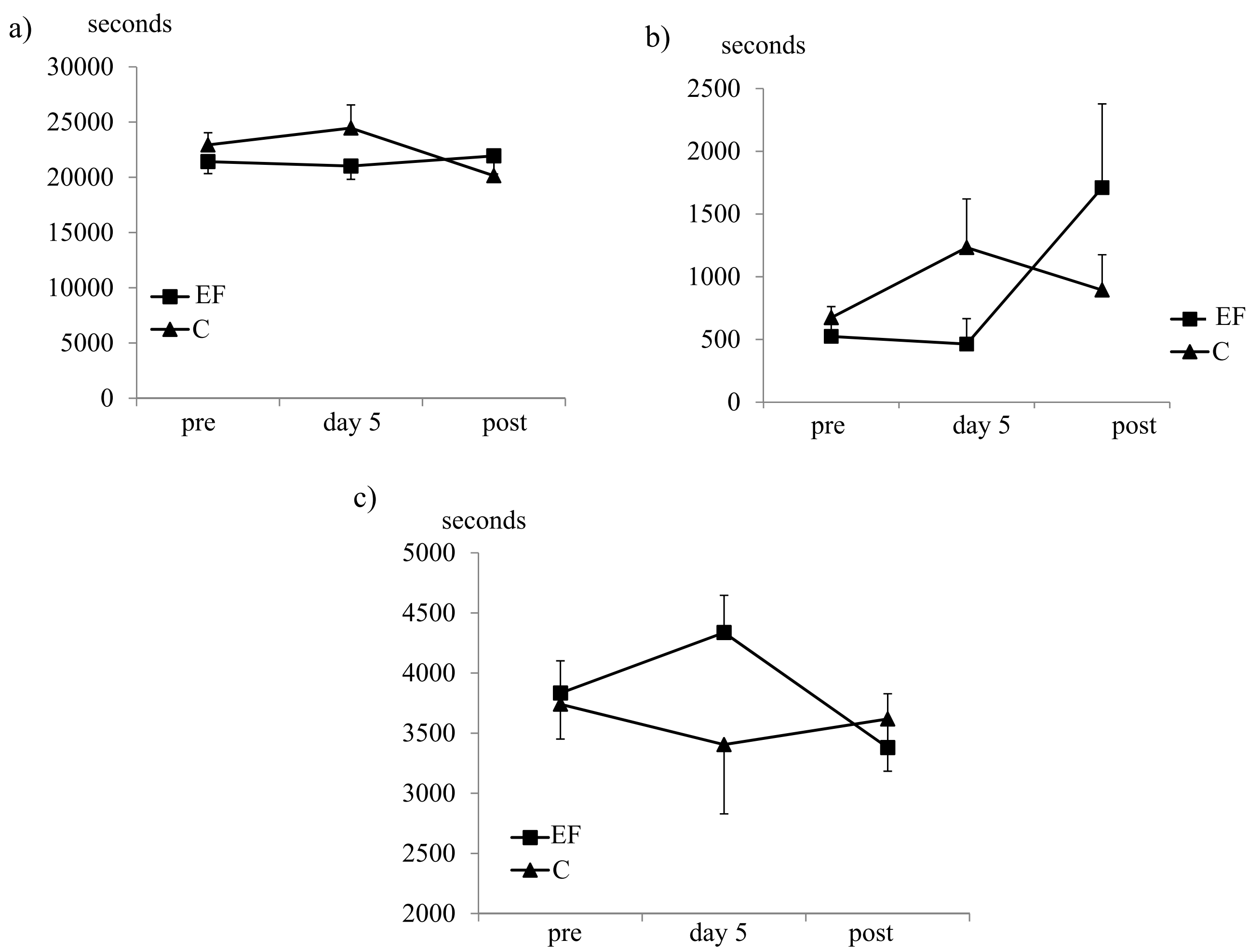

Fig. (3). Effect of electric field exposure assessed by sleep-scan. **a**) Transition of total sleep time, **b**) Transition of duration of nocturnal awakening, **c**) Transition of duration of deep sleep time, EF: Group with EF intervention (n = 9), C: Group with sham treatment (n = 10), Pre: before intervention, Post: at 2 days after completion of intervention. Values are expressed as mean ± SEM.

Table 4. Improvement ratio for each parameter of sleep-scan.

Parameters	Group	Improvement (+) Number of Subjects	Improvement (-) Number of Subjects	Improvement Ratio	*P*
Total sleep time	EF	4	5	44%	
	C	7	3	70%	0.26
Duration of nocturnal awakening	EF	8	1	89%	
	C	5	5	50%	0.07
Duration of deep sleep time	EF	6	3	67%	
	C	6	4	60%	0.76

mellitus [19, 20], atherosclerosis [21], cardiovascular disease [22, 23], dementia [24], and depression [25]. Also, not only morbidity but even mortality has been reported in patients with sleep disorder [26]. Thus, the adverse impact of sleep disorder is enormous in the fields of psychological health, physical health and cognitive function. Sleep disorder has become both a significant health issue and a social issue to be solved, because the cost of sleep disorder is tens of billions of dollars annually [27, 28]. Therefore, establishment of effective treatment for sleep disorder is still a global concern [29]. Moreover, recent reports demonstrated that approximately 9.5% of college students met the criteria for insomnia [30], and that sleep disorder is a significant problem even in young adults [31]. In the present clinical trial, we employed college students because they have no serious disease and do not take sleeping drugs or other medication.

Current major therapeutic interventions to improve sleep quality include pharmacotherapy with sleeping drugs and cognitive-behavioral therapy. Among various sleeping drugs, benzodiazepines are most popularly prescribed. Although benzodiazepines are safe and effective for short-term relief of sleep disorder, they are often prescribed long-term and their more than few adverse events including overdose, cognitive impairment, daytime drowsiness, falls, and fractures often outweigh their benefits [32]. Especially, dependence and withdrawal symptoms are highlighted as a serious problem [33]. Cognitive-behavioral therapy, which is a representative psychological approach, has also been limited by a poor quality evidence base and lack of demonstration of consistent benefit. Therefore, conventional treatment using pharmacological drugs and behavioral therapy for sleep disorder is neither sufficient nor satisfactory despite its medical and social importance. Under such situations, safe, non-invasive, convenient and effective treatment is needed, and is under investigation in the field of complementary and alternative medicine. Indeed, acupuncture and inhalation aromatherapy are already accepted, especially in western countries. Some clinical trials have suggested the usefulness of such alternative treatments [34-36], and potential mechanisms underlying the effectiveness of acupuncture have been reported [37-39]. The beneficial effect of acupuncture on sleep disorder was suggested to be mediated by a variety of neurotransmitters including melatonin [37], β-endorphin [38] and gamma-aminobutyric acid [39], although these findings are still far from conclusive.

On the other hand, in the present study, we demonstrated electric field therapy as a potential complementary treatment. A therapeutic device designed to expose patients to high voltage electric potential has been developed and is widely used in Japan. Electric field therapy using this apparatus has been suggested to have beneficial effects on stiff shoulders, constipation, chronic pain and sleep disorder [40-44]. However, despite the reported beneficial effects, these effects are not still fully understood because of lack of adequate basic experiments and insufficient clinical studies due to the small number of recruited subjects, poorly designed protocols and lack of rigorous analytical methods. Among these symptoms, we especially focused on the effect of electric field therapy on sleep disorder, because exposure to an electric field was reported to affect the expression of sleep-related molecules [5, 8]. As there has been no reported randomized clinical trial to investigate the effect of electric field therapy on sleep disorder, we designed a protocol for a randomized, single-blinded, sham-controlled trial in this study. To our knowledge, this is the first report comparing subjects received electric field therapy to subjects with sham treatment.

Concerning evaluation of sleep quality, subjective symptoms and a feeling of satisfaction are important and more reliable than objective parameters obtained from a device such as sleep-scan and polysomnography, because they are not essentially accurate and reflect mainly sleep quantity rather than quality. Thus, we placed emphasis on assessment of subjective symptoms in this study. Interestingly, electric field exposure improved subjective symptoms related to sleeplessness, assessed by OSA sleep inventory MA version. After 5 days of 30 minutes of exposure intervention a day, significant improvement in scores of three factors (sleepiness on rising, refreshing, and sleep length) were observed, as compared to baseline before intervention. Also, scores increased in a time-dependent manner, suggesting an accumulating effect of electric field exposure. Importantly, these scores of subjects treated with electric field exposure at 5 days were significantly higher than those of subjects with sham treatment. Moreover, the improvement ratios for these three factors were significantly higher in the group treated with electric field exposure than in the sham-treated group. These data suggest that the observed beneficial effect of electric field exposure on sleep disorder is beyond a placebo effect. In addition, the improvement of subjective symptoms after the intervention is partially supported by objective data obtained from sleep-scan. Although there was no significant difference in total sleep time, duration of nocturnal awakening and duration of deep sleep time between the group treated with electric field exposure and the sham-treated group, a high improvement ratio for duration of nocturnal awakening was observed in the group treated with electric field exposure as compared to the sham-treated group. The reduction of duration of nocturnal awakening may contribute to subjective improvement and better sleep quality. Overall, the results from this study provide evidence suggesting the effectiveness of electric field therapy.

Comparison of OSA scores of subjects treated with electric field exposure with average scores of 670 healthy adults [9] provide an interesting observation. The average score of each parameter was as follows; Factor I: 21±7.5, Factor II: 21.0±6.8, Factor III: 23.3±7.4, Factor IV: 20.8±7.6, and Factor V: 21.4±7.2. On the other hand, the change in score of each parameter after intervention was as follows; Factor I: from 12.4±4.0 to 18.1±6.5, Factor II: from 17.0±3.8 to 17.8±7.1, Factor III: from 19.6±6.3 to 21.7±6.4, Factor IV: from 14.0±3.3 to 20.3±5.3, and Factor V: from 14.3±6.3 to 21.3±7.7. As shown in these data, each score at baseline before intervention tended to be lower than each average score, and scores of Factor I, IV and V were elevated to close to the average after 5 days of electric field exposure. This comparison is a reference to the end, because the average scores of 670 healthy adults are obtained from people ranged from 26 to 75 in age [9] and ages of subjects in our study are between 18 and 25. However, this observation would support the beneficial effect of electric field therapy on sleep disorder, in addition to the present data.

How electric potential acts on the human body and the mechanism of the effect presented in the current study are still unclear. However, a hypothesis can be built from some previous literature showing that electric field exposure affects expression of various substances in the living body. The previous report of animal experiments demonstrated that exposure of mice to an electric field reduced stress-induced glucocorticoid level in a voltage- and exposure duration-dependent manner [8]. Also, it was reported that exposure of healthy humans to an electric field increases plasma β-endorphin level [5]. Reduction of glucocorticoid and β-endorphin are reported to be related to sleep deprivation [45]. Additionally, it was suggested that electric acupuncture results in enhancement of sleep, accompanied by an increase in the concentration of β-endorphin [36]. Thus, the beneficial effect of electric field therapy on sleep disorder may be mediated through induction of glucocorticoid and β-endorphin. This is one of the conceivable hypotheses. More basic research is needed.

This study has a few limitations. First, because the number of participants was small, this trial is no better than a pilot study despite its randomization and blinded design. This is the weakest point of this study. Second, the subjects recruited in this study were limited to college students aged from 18 to 25. Further study in wider generations is needed to establish the utility of electric field therapy for practical use. Third, there were not enough parameters employed in the present study. Other established parameters that evaluate subjective symptoms related to sleep disorder and sleep quality, such as the Pittsburgh Sleep Quality Index (Pittsburgh questionnaire), Insomnia Severity Index (Insomnia index), Epworth Sleepiness Scale (Epworth scale) and the sleep item of the Roland and Morris Disability Questionnaire (Roland item) [46], are needed in further clinical trials. Fourth, various clinical settings and study protocols should be evaluated for detail investigation of effect of EF exposure on sleep disorder. It is still unclear from this study when effect of EF exposure is peaked, how is the effect at more than 5 days, and how long the effect sustains after stopping EF exposure. Also, suitable condition of EF exposure, such as duration of EF exposure and position of subjects (seating or lying), should be evaluated in further studies. Finally, there is still a lack of basic experiments about the biological effect of exposure to an electric field. To establish a device that can generate an electric field for practical use, more rigorous methodology and an integrated approach to evaluate both clinical and basic research evidence are required for future studies.

CONCLUSION

In conclusion, the present study demonstrated that electric field exposure over five consecutive days improved subjective symptoms related to sleeplessness, as compared to baseline and sham treatment. Improvement ratios were significantly higher in the group treated with electric field exposure than in the sham-treated group, suggesting its beneficial effect on sleep disorder beyond a placebo effect. Also, a significantly higher improvement ratio for duration of nocturnal awakening, assessed by sleep-scan, was observed in the group treated with electric field exposure as compared to the sham-treated group. Overall, the present clinical study suggests a therapeutic effect of electric field therapy on sleep disorder in young adults. The beneficial effect of electric field therapy on sleep disorder may raise the possibility of a new approach as complementary treatment besides conventional therapy.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study protocol was approved by the Ethics Committee for Clinical Investigation of Morinomiya University of Medical Sciences (Permit Number: 2015-33). The study was performed in compliance with these institutional guidelines.

HUMAN AND ANIMAL RIGHTS

No animal is used in this research.

All of the participants gave written informed consent before entering the study, which was conducted in accordance with the Declaration of Helsinki.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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