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Source separation on single channel EEG: A pilot study on effect of transcranial alternating current stimulation on scalp meridian

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***Abstract*— Brain electrical stimulation has shown the capability to modulate neural activities in a variety of ways. Compared with transcranial direct current stimulation(tDCS), transcranial alternating current stimulation (tACS) may affect brain activities differently through a frequency-based mechanism. This pilot study applied tACS to the scalp following the meridian (Jingluo) of traditional Chinese medicine to explore its potential neural modulation effect. A wearable electroencephalogram (EEG) device was used to measure the frontal activity in a female participant before and after tACS longitudinally. A combined method of singular spectrum analysis (SSA)-independent components analysis (ICA) was applied to separate potential artifacts from ocular and other irrelevant sources. The results demonstrated that SSA-ICA could effectively separate signals from different sources especially the ocular artifact. EEG spectrum analysis showed that short-term tACS could increase the power of delta waves. This study has good implications for the use of tACS and SSA-ICA method for the study of brain activities. Future research is needed to refine more optimum parameters of tACS and SSA-ICA to make the evidence more solid.**

***Clinical Relevance*— tACS may influence the brain wave oscillations through the frequency-based mechanism. SSA-ICA method helps to broaden the use of wearable EEG devices for various clinical applications.**

I. INTRODUCTION

The technique of transcranial electrical stimulation becomes more popular as numerous studies found unequivocal evidence that electric stimulation of the brain could improve perception and cognitive functions [1, 2]. On the other hand, the parameters used to stimulate the brain vary from one study to another, while far from perfection. Numerous studies investigated the effect of transcranial direct current stimulation (tDCS) on neural modulation [3]. However, it is postulated that frequency-based brain stimulation might be an alternative way to manipulate the brain's function [4]. Aside from the location of electrical stimulation, the frequency of the stimuli has different effects. For example, high-frequency electrical stimuli is efficient to treat depression or emotion disorder, while lower frequency is suitable for pain release [5].

On the other hand, a technique evolving from traditional Chinese medicine (TCM) known as, electroacupuncture (EA), combines the use of electric stimulation and acupuncture on specific acupoints, has been applied to treat patients for decades. It has been found more effective than traditional acupuncture alone. For example, recent work using electric stimulation on acupuncture in depression found that it could improve the Hamilton depression scale [6].
In this study, we investigated whether the traditional massage on the meridian (Jingluo) of TCM, plus tACS, could modulate neural activity at the frontal lobe as monitored by EEG.

Frontal lobe activities play an important role in attention, higher cognitive functions, and emotion regulation, and it has great relevance in clinical applications on affective, attentional disorders. A single-channel EEG device is a convenient way to monitor frontal lobe activities [7, 8]. However, this kind of wearable EEG is often mixed with ocular or other muscle artefacts. Independent component analysis (ICA) can be used to separate different signal sources. In this study, we aimed to apply singular spectrum analysis (SSA) to map the original EEG signal into multivariate data before ICA. One previous study demonstrated the SSA-ICA could be more effective than other methods such as adaptive noise canceler-ICA, wavelet-ICA, and ensemble empirical mode decomposition-ICA methods [9]. We hypothesized that the utilization of higher-order statistics by combining SSA and ICA could make a robust source separation of ocular and other artefacts in single-channel EEG before and after tACS treatment.

II. METHOD

A single-channel EEG device (uMindSleep) was used to collect the frontal EEG before and after each session of tACS treatment. The tACS machine is the one normally used in the daily treatment center (Universal Energy Machine). The parameters of tACS stimuli included the following: alternating frequency, 100Hz; voltage, 30 v; duration, 50 uS.

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Each session lasted 30 minutes. The tACS treatment was mainly applied to the scalp part of the bladder meridian of foot in TCM. A female participant of 38 years old was recruited for repeated tACS treatment for 17 sessions. She had no neurological disease or psychiatric disease that might affect her neurological function. The participant signed the consent form as approved by the university ethics committee. The EEG data were collected at the pre-rest state and post-rest state, both with closed-eye and supine positions, each lasting 20 minutes. The EEG signal was measured at the frontal lobe, roughly at the position of Fpz.

Figure 1. Illustration of experiment procedure. Single-channel EEG data were collected for 20 minutes before and after the tACS treatment, which last for about 30 minutes.

Different methods, including the SSA-ICA and other ICA methods, were applied to the single-channel EEG data to explore the best result for source separation. For SSA-ICA method, we also examined different combinations of component number and window length to explore the best parameters for source separation.

The SSA-ICA method followed two main steps of decomposition and reconstruction, with six step-by-step algorithms listed in the following [9]: 1) choose the number of decompositions and window length; 2) SSA is applied to decompose the EEG signal into lower and higher frequency components; 3) repeated step 2 on low-frequency components to construct a matrix of the multivariate data; 4) FastICA is applied to the matrix and get independent components (ICs); 5) multiply ICs with corresponding column vector, 6) make the unintended vector zeros before summing up the rest to get a clean EEG signal.

Through these six steps, optimum parameters of ICA were obtained, which were then applied to all single-channel EEG. Major sources of ocular movement and other artifacts were rejected. The rest EEG data were weighted and summed to form a clean EEG signal after the ICA.

Spectrum analysis was applied to obtain the absolute powers of delta (1-4Hz), theta (4-8Hz), alpha (8-12Hz), beta (12-24Hz), gamma waves (24-40Hz), following the standard wave range. The segment window of EEG is 2 seconds. Paired t-test was used to assess the effect of tACS, and $p < 0.05$ was set as a significant level of statistical comparison.

III. RESULTS

Fifteen single-channel EEG data sets were obtained eventually, as two sessions of data were not suitable for analysis due to extreme noise. SSA-ICA was applied after the manual artifact rejection of obvious body movement or other excessive artefacts. Different combinations of component number and window length were explored. The results show that 10 components with 20 second duration is an optimum combination to yield a good and efficient way of ICA.

Figure 2. Results of SSA-ICA on single-channel EEG

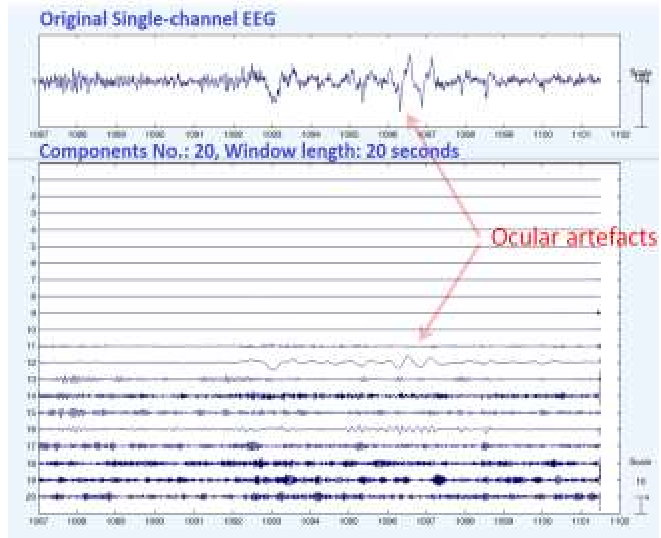

Figure 2. It demonstrates that SSA-ICA with 20 components and 20 second window length could separate the ocular artefacts.

Figure 3. SSA-ICA with different window length

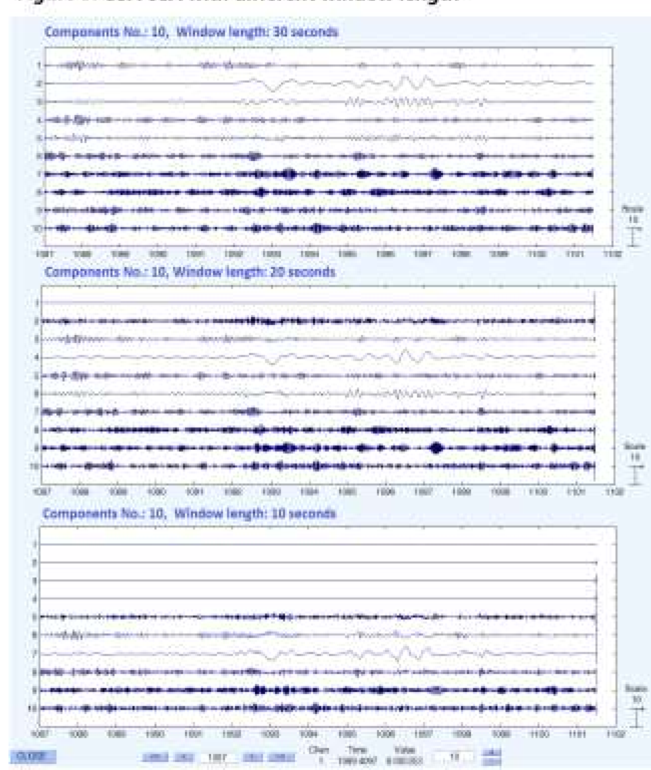

Figure 3. It demonstrates SSA-ICA separation using three different combinations of component number (10, 10, 10) and window length (30s, 20s, 10s) in the upper, middle, and lower parts of the figure, respectively. With 10 components and 20 s being the optimum parameters.

Nonetheless, different component numbers and window lengths can affect the efficacy of SSA-ICA. An excessive number of components, e.g., 30, or too long duration did not have a better result but consuming a longer calculation time. See figure 3.

When the component number and window length is not optimum, the IC may become a bare line that contains little information, as shown in the lower part of figure 3. Usually, the selection of component number and window length is based on the rationale of the original signal, the purpose of separation, and the final outcome of SSA-ICA.

After SSA-ICA, ICs of the ocular artefact and apparent artefact of muscle and movement were deleted. Then the rest of ICs were used to generate the clean EEG data. Spectrum analysis on the cleaned EEG data showed the absolute delta wave power became higher after a short-term tACS. Other frequency bands did not show significant differences.

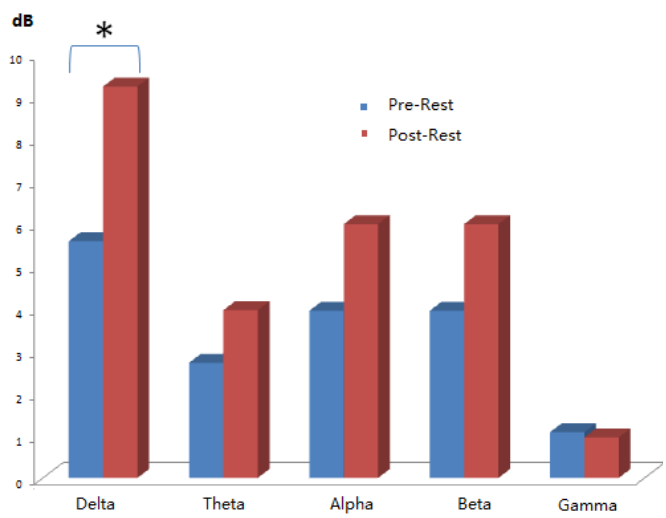

Figure 4. It demonstrates an increased delta wave (absolute power) after tACS treatment. Pre-rest, resting-state EEG before tACS treatment, post-rest, resting-state EEG after tACS treatment. (Y-axis unit dB).

IV. DISCUSSION

This pilot study demonstrated that the SSA-ICA application on single-channel EEG data could effectively separate the source of the ocular artifact with optimum parameters. For the current single-channel EEG datasets, 10 components with 20 seconds window length were found to be optimum, while an excessive number of the component or long window length may not increase the efficacy of the SSA-ICA method. This finding has an important implication, as the use of single-channel EEG devices is becoming more popular nowadays, and the momentum for its use can grow in the near future [10-13].

One major problem with single-channel EEG is that the signal-to-noise ratio is rather low when compared to those of multiple-channel systems used in clinics and academia [14, 15]. Theoretically, data with a mono source is more difficult to be analyzed with ICA, which needs multi-channel to be performed. ICA is commonly used in EEG artifacts reduction. The current SSA-ICA method could combine the wave-let and other methods and enabled the possibility to conduct ICA in single-channel EEG. In line with several analysis methods of single-channel EEG data [9, 16], the current results showed that SSA-ICA could be an optimum one for such application when optimal parameters are applied.

Meridian is an important concept and has a long history in TCM. The relatively newer application of electrical stimulation along with the meridian is has been found effective in clinical settings [17, 18]. Currently, Foot Tai Yang Bladder Meridian was chosen for its plenty of acupoints in the head, and Baihui acupoint was also involved in the treatment. This meridian is assumed to release headache or anxiety. This is important given that stress is popular in today's society. In an EEG study, stress is characterized by increased fast frequency bands such as gamma waves while decreased slow waves, including the theta and delta waves [19, 20].

The current study demonstrated that short-term tACS could effectively increase the delta wave and potentially can release stress and anxiety in the individuals. The application of tACS is important complementation of the popular usage of tDCS. A variety of brain functional changes were found after tDCS. One problem with tDCS is that it only influences the local field potential, while tACS is rhythm-based and probably can change the frequency through brain wave oscillations. tACS has a different mechanism from tDCS and may affect the brain function more effectively, and more studies on these aspects need to make its application more solid.

V. CONCLUSION

This pilot study examined the effect of tACS following TCM Jingluo on frontal EEG activities. A single-channel EEG device was used and the SSA-ICA method was applied to the EEG signal to separate artifacts from ocular movement and other sources successfully. The results showed that tACS may increase the absolute slow delta wave power in the frontal lobe, which indicated its potential use in stress reduction. Future studies are needed to improve the parameters used in tACS as well as explore more optimum parameters for SSA-ICA method for solid application.

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