Short Time Effect of Delta Oscillation under Microcurrent Transcutaneous Electrical Nerve Stimulation at ST36

Shunan Li, Donghui Li, Huiyan Li, Jiang Wang*

Abstract—**This paper was to study the short time effect of Delta brain oscillation under microcurrent transcutaneous electrical nerve stimulation (MTENS) at ST36 (Zusanli). The 64-channal electroencephalograph (EEG) signals from 12 healthy volunteers were recorded including baseline stage, during stimulation and after stimulation. Autoregressive (AR) Burg method was used to estimate the power spectrum. Then power variation rate (PVR) was calculated to quantify the effects compared with the baseline in Delta band. The results showed that MTENS at ST36 on right side led to increased Delta band power in left frontal.**

I. Introduction

Peripheral nerve stimulation can elicit different physiologic responses in the central nervous system (CNS) and neuroendocrine systems. Transcutaneous electrical nerve stimulation (TENS), patented in the United States in 1974, is a widely used neuromodulation procedure to relieve acute and chronic pain clinically[1]. Electroacupuncture (EA) is TENS at acupunctures. Wang et al. investigated brain oscillations regulated by EA using a postincisional pain model of rat[2]. Yi studied the effect of seizure suppression by acupuncture at Feng-Chi (GB20) by employing an animal model of focal epilepsy[3]. Kang et al. investigated the effects of EA on epilepsy to determine the specific acupoints and optimal stimulation parameters[4]. Li et al. found that stimulation at Neiguan(PC6) and Shenmen (HT7) affected theta-band phase synchronization in humans[5]. Wu et al. proved that TENS at LI4 and LI11 increased current perception thresholds values in the mental foramen area[6]. Chen et al. suggested that LI4 electrical stimulation modulates limbic vinculum[7]. Chang et al. demonstrated that EA stimulus at St36 has the potential to influence gastric mucous substances and enteroendocrine cells that subsequently modulate digestive functions[8].

However, electrical stimulation intensities applying to humans in these studies are determined as sensory level or motor level. In sensory level, the electric current is being increased until the subject feels a comfortable tingling (perceived with high frequency) or tapping (perceived with low frequency) sensation without motor contraction. The electric current of this type of electrical stimulation is usually more than 10mA; and with motor level TENS, the intensity is being increased to produce a motor contraction[1]. Microcurrent electrical stimulation below sensory level is used in transcranial electrical stimulation (TES) while there are no data to support the effects of peripheral nerve stimulation[1, 9]. Microcurrent stimulation is safer than sensory level stimulation to avoid noxious sensation because of the smaller current. However, it's not clear whether it works to modulate the brain electrical activity when applying microcurrent stimulation on peripheral nerve as well as on central nerves.

The aim of the present study was to examine (a) whether microcurrent transcutaneous electrical nerve stimulation (MTENS) at ST36 modulates Delta Oscillation is comparable with placebo stimulation; (b) whether Delta band power variation only presents during stimulation or last to the post stage; (c) whether specific cortices areas are affected.

This study used 64-channel EEG recording, AR Burg spectra analysis method to estimate the modulation effects under below sensory level electrical stimulation at ST 36. The rest of the paper was organized as follows. First, the experiments and analysis methods were described. Second, we presented corresponding data analysis and the results. Finally, the results were discussed and conclusions were given.

II. Materials and Methods

A. Subjects

Twelve right-handed healthy volunteers (mean age±SD: 24.3±2.7years; six males and six females, with no or little acupuncture experience) were recruited in the study. Subjects were excluded from the study if they had any medical history of neurologic or psychiatric disorders, or with any other factors that affect EEG activities (e.g., abusing alcohol or illicit drugs; using medication). The study was approved by the local ethics committee, and each subject has been provided with informed consent for the adequate understanding of the purpose and procedure. Written consents were obtained from all subjects in accordance with the Helsinki Declaration..

B. Experiments

The subjects were asked to sit in an armchair throughout the experiment in a quiet room (mean temperature: 23 °C), and were instructed to fully relaxed with eyes closed. However, they were required to maintain awareness. Electronic acupuncture stimulator (Hwato: SDX-Ⅱ Never and Muscle Stimulator) was used. A pair of skin electrodes were placed on the selected points: the negative one, 3×3 cm^2, placed on ST36; the positive one, 5×5 cm^2, placed 100mm below ST36. A 100Ω resistance was cascaded between the

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stimulator and the positive electrode to monitor the real-time stimulating current with an oscilloscope (Tektronix TDS 2012B) (see figure 1).

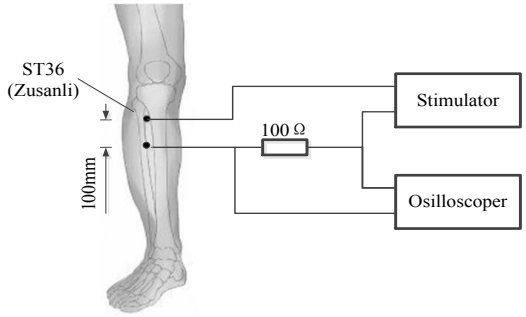

Figure 1. *Stimulation site and instruments connection*

The experiment included two sessions: MTENS session and placebo session. Each subject attended both sessions that were at least one week apart from each other. The subjects were informed to be stimulated twice. There were three stages in each session: 5 min baseline; 5min stimulation; 5 min post-stimulation (see figure2). In EA stimulation session, the simulation waveform was "Lilly" wave with the width of 0.16ms widely used in TENS. We used 100Hz stimulations it has been proved that 100Hz stimulations show significant effects in sensory level experiments[4, 6, 7, 10]. The amplitude of stimulation was 1mA with the current density of 0.11mA/cm^2 through 9cm^2 electrode (see figure 3). In placebo session, the stimulating current was turned off.

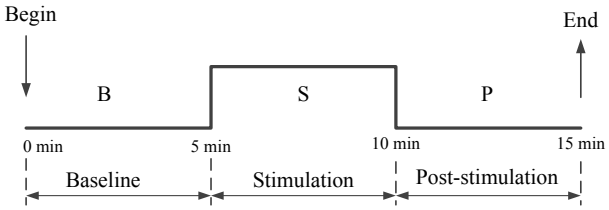

Figure 2. *Stimulation process*

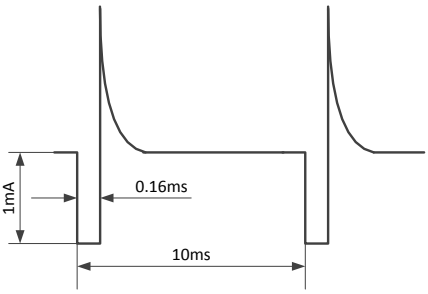

Figure 3. *Stimulation waveforms*

. C. EEG recording

64-channel EEG signals and 2-channel electro- oculogram (EOG) signals were continuously recorded with Phoenix digital EEG System (Phoenix EMS 128, Austria). The Ag–AgCl electrodesweremounted according to the extended 10-20 international system[11](see figure 4) and electrode impedance was kept lower than 5 kΩ. Reference electrodes A1 and A2wereplaced on both earlobes. Bilateral EOG signals were recorded from the horizontal and vertical sites to monitor blinking and eye movements. EEG data were sampled at 512 Hz with bandpass filter (0.05–70Hz), and filtered with 0.1-48Hz bandpass filter in preprocessing.

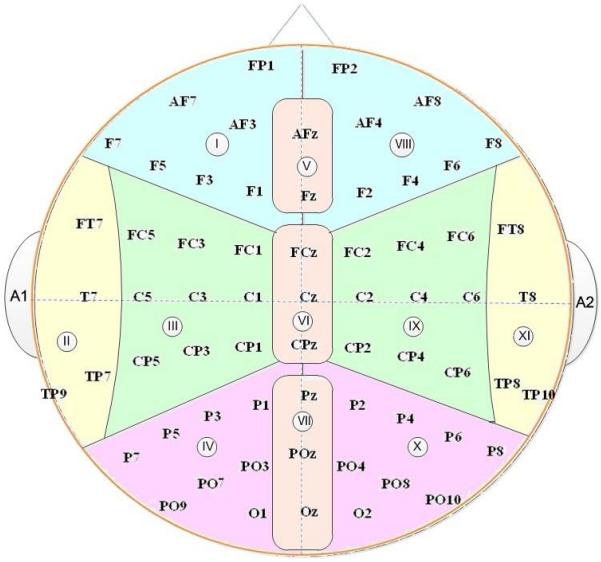

Figure 4. E*xtended 10-20 international system and sub-brain regions*

EEG signals were recorded continuously. The length of the EEG recording was 15 min for each subject in one session. The EEG data were inspected to select an 8-s artefact-free segment from every 30-s signals by an expert to eliminate the effects of head movements and muscular activity. In total, 720 (10×3×2×12=720) EEG segments were obtained, with 10 segments selected in one stage per subject in one session.

D. Data analysis methods

EEG data were analysed by the Burg's method for AR spectral estimation. The absolute PSD estimation using Burgs method is

$$\hat{P}_{BURG}(f)=\frac{\hat{e}_p}{\left|1+\sum_{k=1}^{p}\hat{a}_p e^{-j2\pi fk}\right|} \qquad (1)$$

where $\hat{e}_p$ is the total least squares error, p is the model order of AR method[12]. The model order is ten in our study.

Then the absolute power (μv^2) of Delta band (0.5Hz to 3.5Hz) at each electrode were obtained by integration method.

The power in a sub-brain region is the total power of the electrodes in corresponding brain areas. Eleven sub-brain regions were given as table 1, including left frontal lobe (LF), left temporal lobe (LT), Left central lobe (LC), left parietal occipital lobe (LPO), frontal lobe (F), central lobe (C), Parietal occipital lobe (PO), right frontal lobe (RF), right central lobe (RC), right temporal lobe (RT), right parietal occipital lobe (RPO).

TABLE I. THE SIGNIFICANCE OF EFFECTS ON PVR

No.	Sub-brain Regions	Electrodes
I	left frontal (LF)	FP1, AF3, AF7, F1, F3, F5, F7
II	left temporal (LT)	FT7, T7, TP7, TP9
III	Left central (LC)	FC1, FC3, FC5, C1, C3, C5, CP1, CP3, CP5
IV	left parietal occipital (LPO)	P1, P3, P5, P7, PO3, PO7, PO9, O1
V	frontal (F)	AFz, Fz
VI	central (C)	FCz, Cz, CPz,
VII	parietal occipital (PO)	Pz, POz, Oz
VIII	right frontal (RF)	FP2, AF4, AF8, F2, F4, F6, F8
IX	right central (RC)	FC2, FC4, FC6, C2, C4, C6, CP2, CP4, CP6
X	right temporal (RT)	FT8, T8, TP8, TP10
XI	right parietal occipital (RPO)	P2, P4, P6, P8, PO4, PO8, PO10, O2

The power variation rate (PVR) was calculated to character the stimulation effects on brain excitability in each condition at the corresponding stage and baseline stage.

$$PVR_{stage} = \ln \frac{P_{stage}}{p_{base}} \qquad (2)$$

Then statistical analysis was performed by two-way ANOVA to find specific bands and regions, while $P < 0.05$ was considered to be significant. At last we use PVR to quantify the effects on focal rhythm and area.

III. RESULTS AND DISCUSSION

The absolute powers in Delta band of the 64-channal EEG signals were estimated with AR Burg method. The power topographies (averaged over 12 subjects) at the three stages in EA and Placebo sessions were presented in figure 5. PVR of Delta band in each sub-region was calculated as shown in figure 6. The results of two-way ANOVA on PVR indicated the significance (table 2). The statistical results indicated the significant effects in LF. The Delta PVR in LF showed significant condition by stage effects (P = 0.0031), session effects (P=1.07E-5), interaction effects (p=0.0412). Left front was the target area when stimulating at the right leg.

Figure 7 shows time series of PVR in Delta band at LF. In EA session, the power increased in EA/S and continued increasing after stimulation, then keeping the level till the end of data collection. In placebo session, Delta activity decreases slowly.

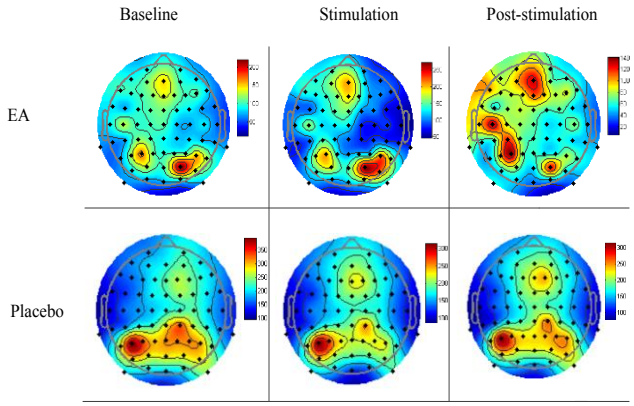

Figure 5. *Topographies of Delta band power spectrum*

TABLE II. THE SIGNIFICANCE OF EFFECTS ON PVR

Region	Factor	P
LF	Session	1.07E-05*
	Stage	0.0031*
	Se&St	0.0412*
LT	Session	4.73E-05*
	Stage	0.133
	Se&St	0.7132
LC	Session	4.44E-06*
	Stage	0.0163*
	Se&St	0.3326
LPO	Session	0.00027*
	Stage	0.1068
	Se&St	0.9954
F	Session	3.19E-05*
	Stage	0.0076*
	Se&St	0.0762
C	Session	1.44E-06*
	Stage	0.0273*
	Se&St	0.7314
PO	Session	0.0901*
	Stage	0.519
	Se&St	0.8092
RF	Session	0.0096*
	Stage	0.0393*
	Se&St	0.0921
RC	Session	0.032*
	Stage	0.3073
	Se&St	0.6561
RT	Session	0.0799
	Stage	0.1307
	Se&St	0.9973
RPO	Session	0.1954
	Stage	0.1523
	Se&St	0.6186

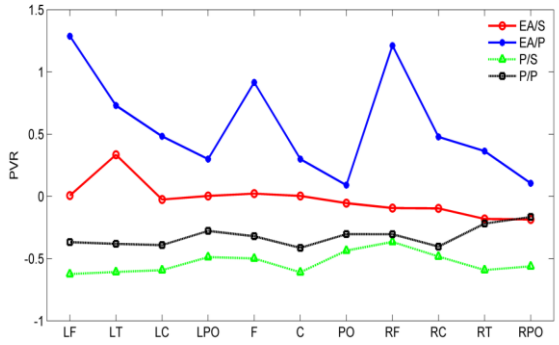

Figure 6. *PVR in sub-brain regions*

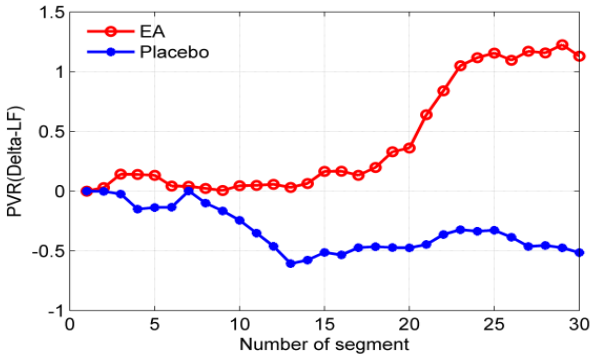

Figure 7. *Time series of PVR in LF*

ST36, the stimulation site of this study lies at 5 mm below the head of the fibula under the knee joint, and 2 mm lateral to the anterior tubercle of the tibia[11]. This juncture is rich in peripheral nerve extension including the sensory nerve and muscle tendon, such as lateral sural cutaneous nerve, deep peroneal nerve, posterior tibial nerve and their ramifications, with great focal electrical conductivity. The observed modulation effects in this study could be due to the changes caused by the nerve conduction and excitability.

MTENS at ST36 induced brain oscillations in the Delta band significantly. It was observed from comparing the PVR of EA and Placebo groups in this study, while LF was the focal area coinciding with the somatosensory cross innervation.

Delta oscillations dominate in EEGs of lower vertebrates, which may be involved in integration of cerebral activity with homeostatic processes, generating in anterior medial frontal cortex in waking adults[13]. If delta oscillations are implicated in coordination of behavior with basic biological and homeostatic needs, they must participate in synchronization of brain activity with autonomic functions[13].

IV. Conclusion

We designed an experiment to study the short effects of MTENS at ST36 on right leg. The Burg's method for AR spectral estimation was used to characterize EEG signals. PVR was calculated to evaluate the affects from spatial and temporal aspects. Our study suggested that MTENS at ST36 on right leg can enhance Delta rhythm in left frontal from stimulation stage and maintain the enhancement until the end of the EEG recording. It demonstrates that MTENS can modulate brain activities through somatosensory nerves and the effects can last to post-stimulation.

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