The Effect of tDCS on ERD Potentials: A Randomized, Double-Blind Placebo Controlled Study

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Abstract — **In this paper, we report the results of a study on the post-intervention effects of applying anodal transcranial Direct Current Stimulation (tDCS) on the intensity of motor Event Related Desynchronization. Ten subjects were given 15 minutes of sham and 1.5 mA tDCS on two separate occasions in randomized order in a double blind setting. Post-intervention EEG was then recorded while subjects were asked to perform imagined motor imagery. Results show that the intensity of 8-13Hz Mu rhythms exhibited significant difference between the sham and tDCS groups, with an average of 24.13 μV^2 for sham and 32.57 μV^2 for tDCS with a measured t-test *p* value of 0.03.**

Keywords—Brain Computer Interface; ERD potentials; tDCS; Mu rythms; Stroke.

I. INTRODUCTION

In the UK, an estimated 152,000 people have a stroke every year [1]. Strokes often result in loss of cognitive and motor functions which undermines the quality of life of sufferers. Although the condition affects mostly those in the over 65 population, it presents a significant financial (£8.9 billion) and social cost to society [2]. EEG based biofeedback has been proposed as a possible approach to improve rehabilitation, especially to recover motor function through stimulating neuroplasticity. These methods use technology from Brain Computer Interfacing (BCI) to provide feedback to patients in order to reinforce correct learning. A review of BCI stroke rehabilitation methodology is presented in [3].

Favorable results have been found when assessing Event Related Desynchronization (ERD) as an indicator of recovery and for its use with BCI biofeedback in stroke rehabilitation [4]. Effectively The technology is used to facilitate the coupling of ERD to an orthosis action [5, 6]. Unfortunately the ERD of stroke survivors has been shown to be lower than normal [7], with acute cortical infarcts (strokes) decreasing the ERD of alpha wave oscillations for the affected pericentral sensorimotor areas [8] bringing in to doubt whether the intensity of ERD in stroke survivors is large enough to be used as a BCI system control signal for biofeedback training.

Recently, there has been a growing academic interest in neuro-stimulation techniques such as Trans-Cranial Direct Current Simulation (tDCS) where a number of studies seem to suggest it can be slightly, but temporarily, amplified to heighten responsiveness [9-12] which may allow for better and faster rehabilitation of stroke patients.

tDCS is a non-invasive brain stimulation tool. It modulates cortical excitability through the application of weak electrical currents in the form of direct current brain polarization. It delivers low-intensity, direct current to cortical areas facilitating or inhibiting spontaneous neuronal activity[13]. Depending on direct current (DC) polarity, neuronal firing rates increase or decrease, with anodal tDCS in most settings increasing, and cathodal tDCS decreasing motor–cortical excitability [14]. In terms of its limitations, the electrical current is delivered through two sponge electrodes soaked in saline solution. Typically, these electrodes have a relatively large surface of 20–35 cm^2 that limits the focality of stimulation, and thus the technology, as it stands, cannot produce temporally focused effects [15] [16]. Further to the low spatial resolution is the fact that the modulation of a particular brain area's response to a certain stimulation reflects a limited view of a large-scale functional network. Consequently, the tDCS method implies that a distinct brain region is involved in computational processes that are in fact part of a more complex system [17]. As of yet, neither detailed mechanisms of how tDCS facilitates recovery from stroke nor optimal parameters of stimulation are well understood [18].

In areas outside the realm of ERD, studies have shown the technology offers improved facilitation of cognitive and motor processing as well as learning in the healthy brain [19]. It has also been suggested that tDCS could be a highly promising technique in human neurorehabilitation, where (re-) learning, or at least preservation of motor and cognitive abilities, is of utmost importance [19]. tDCS has several advantages that render it attractive for clinical use compared to invasive stimulation. The technique is, as stated, non-invasive and elicits only a slight tingling under the

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electrodes. The device is also easy to use, small, allowing it to be attached to the patient, and relatively inexpensive. Research has also been published showing potential for tDCS in patients with neurodegenerative disease, movement disorders, and post-stroke language, attention, or executive deficits [19]. In addition, tDCS offers several advantages that render this tool attractive for neuro-rehabilitation, as compared with other brain stimulation techniques: it is safer than invasive brain stimulation, which is usually associated to higher surgical risks and costs; in comparison to Transcranial Magnetic Stimulation (i.e., TMS), it is less uncomfortable, easier to handle and less expensive [20].

Studies have also demonstrated that tDCS can heighten the magnitude of alpha waves [21-23], and be used in conjunction with BCI [24]. It has also been suggested that there is a potentially beneficial effect of tDCS during rehabilitative motor training of patients suffering from subacute strokes [25]. However, the scale and effect duration of tDCS on ERD potentials is still speculative. The purpose of this study was to investigate the post-intervention effect of tDCS on ERD potentials with the view of assessing its suitability for neuro-rehabilitation of motor functions.

The paper is organized as follows; the experimental protocol is described in the next section then followed by a presentation of the results and a conclusion.

II. METHOD

A. Subject selection

Eleven healthy subjects (age 22 ± 3 years, all right-handed) participated in this study after giving written informed consent. No subject had a history of neurological disease or was receiving any acute or chronic medication affecting the central nervous system. The University of South Wales Ethical Committee approved the investigation.

B. tDCS application protocol

The tDCS, Newronika model HDC, was then fitted according to procedure used by [26] for anodal stimulation. The anodal electrode was placed over the left M1, and the cathodal electrode over the right supraorbital area. Subjects sat in an armless chair, then using measurements of the distance between anion and nasion Cz was found, then 20% of the distance from Cz to the left pre-aurical point was found. This location, C3, was then gelled with EEG high conductivity gel. The temple was also gelled with the same. The tDCS pads were soaked in normal tap water and high conductivity get applied. The pads were placed on C3 and the frontal right lobe and both secured with a plastic band and netted cap.

Each subject underwent two experimental tDCS sessions, one real and one sham separated by a one-week interval. The order of sham and real tDCS was randomized and double blinded. The real tDCS consisted of 1.5mA current applied for 15min. The sham consisted of a dose of 1.5mA ramping up from 0mA to 1.5mA over 10s. 1.5mA was then driven for 8 seconds, before the tDCS automatically turned off. This procedure for the sham trial was conducted to mimic the transient skin sensation at the beginning of actual tDCS without producing any conditioning effects on the brain [27].

Neither the investigator nor the participants were aware which of the dosages were being administered. Participants were not informed that the dosage would be varied for each study (sham, 1.5mA), but were led to believe that the same dosage was being used for each study. They had given written informed consent with ethical approval being obtained for using stimuli up to a maximum dosage of 1.5mA for no longer than 20 minutes The dosage was selected in each experiment by a second investigator who turned the sham button on or off based on a randomly generated binary number. The second investigator did not interact with experiment after applying the switch. The impedance value of the tDCS while operating was checked by the second investigator and remained between 4 kΩ and 9 kΩ for all participants, which was the recommend window given in the tDCS device instructions.

After the application of tDCS or sham stimulation, the EEG electrodes in the cap were connected to the participant using conductive gel. It took between 10 to 15 minutes to fit the cap and apply conductive gel to the electrodes. Once connected, the impedance of each electrode remained at a minimum of 20 kΩ with a typical value of 10kΩ throughout the experiment

C. EEG measurement protocol

EEG signals were recorded from 14 Ag/AgCl disc electrodes (1 cm in diameter) with two reference electrodes at FCz and AFz to the international 10-20 system of electrode placement (Fz, F3, F4, F7, F8, Cz, C3, C4, Pz, P3, P4, P7, P8, Oz). The signal was pre-filtered (0.2-45Hz) and had digital notch filters at 50Hz and 60Hz. The cap was centred on the scalp at Cz midway between the anion and nasion. Cz was checked for its equidistance to both left and right pre-aurical points.

D. ERD Measurement protocol

Subjects were initially asked to sit in a chair with no arm supports and face a computer monitor placed approximately 0.7 m in front of them at eye level. Both arms initially were allowed to dangle freely by their sides. At this point, subjects were shown a tennis ball on the computer monitor screen and asked to use the right hand to grab it, let go, then return their hands to their original position dangling by their side. They would to this physically, clasping the hand within 1 cm of the screen. They were then asked to keep their hand dangling freely by their side and repeat the grasp mentally without moving their arm or hand. The investigator held on to their arm and neck lightly to try and detect any muscular contractions. Subjects were asked to repeat the imagined grasp until no muscular movement was detectable by the investigator. It was made clear to them that they were required to make the mental effort to grab the ball in the same manner they had practiced physically and not just to imagine a video playback of their hand grasping it.

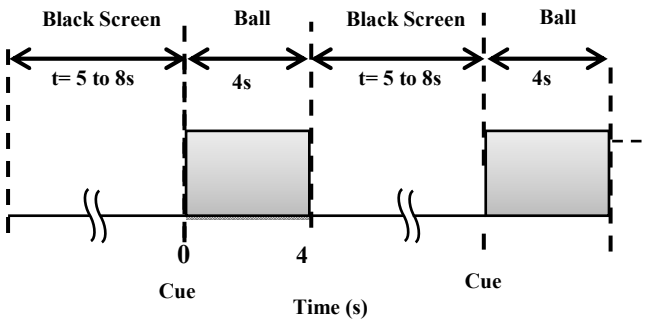

Fig 1. Cue timeline for experiment. The appearance of the first tennis ball is marked as the first boundary condition, seen here as time = 0s. This is followed by a blank screen for 5-8s. After the blank screen, the ball reappears and process repeated for a total of twelve appearances.

They were also asked to try to avoid any further muscular activity including blinking. The researcher told them that if they did accidently blink or flinch, they should ignore it and continue the study. They were informed that the study would be repeated several times and such artifacts would be removed. This was done so as to avoid participants feeling anxious if they accidently made any muscular motions during the study, which could then have had an effect on the remaining results.

Each trial consisted of two slides, a blank black slide which appeared for 5 to 8s (randomized) followed by a black slide with a tennis ball centered on it. The blank black slide signified a rest state to be assumed by the participant. When the tennis ball slide appeared the participant was to make the mental effort of reaching out to the ball, grasping it, letting it go, and returning their arm to their side. All done with no time gaps in between each step.

III. Results

After visual artifact removal, the EEG was filtered between 8 and 13 Hz using a standard FIR filter. This range was selected to isolate the mu rhythm associated with motor imagery modulation of sensorimotor rhythms [11]. The epochs (-1s to 3.5s) were extracted, a baseline removal was run using the time window (-1s to 0s). The epochs were averaged and the power (μV^2) was found for the time windows: -1s to 0s (pre-cue) and 0.5s to 3.5s (Post cue: ERD activation due to mentally reaching, clasping and releasing the ball). All processing was done using EEGLAB [28].

The difference in power, within the 8-13Hz band, for each participant in going from pre-cue to post cue was found and results plot in figure 2. The average power difference for post-tDCS results was 35.48 μV^2, compared with 24.13 μV^2 for sham. Figure 2 shows a clear trend when tDCS is used, with an increased power difference seen for all subjects except for one (subject 4). A paired two-tailed t-test revealed a *p*-value of 0.03. When looking at tDCS and sham as two independent groups using ANOVA analysis, a *p* value 0.15 is observed suggesting the difference in group means may have a lower statistical significance than in the case of paired t-test analysis.

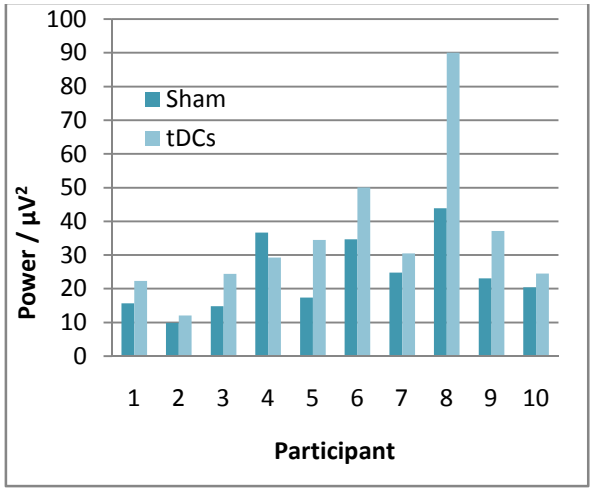

Fig. 2 Comparing the step in ERD power for the C3 pre- and post-motor image cue after participants had undergone either a sham or 1500mA Anodal tDCS. A clear trend of increased power change is seen for all participants post-tDCS except with participant No. 4.

This suggests that inter-subject variation is higher than the consistent tDCS added effect for individual subjects. Thus, caution must be taken when drawing conclusions from these data. The ERSP is presented in figure 4 for C3 averaged for the ten subjects. The ERSP plot, figure 4, displays the contrasted power of the ERD (8-13Hz, occurring around the 400-600ms point) for tDCS when compared to that of sham t-DCS.

IV. Discussion

In the study, a participant would go from a rested (neutral) state, to that of imagining motor imagery - generating an ERD. The power difference seen in the mu band in going from a neutral state to that of imagined motor imagery was measured. This power was found to be consistently higher with the application of tDCS compared to Sham tDCS – except with one participant. The average difference in power for all participants when tDCS was applied was found to be 35.48μV^2 with a standard deviation of 21.64. This can be contrasted with the average power change for the Sham tDCS experiment of 24.13 μV^2 with a standard deviation of 10.95. Thus, it was found that the tDCS increased the power difference by 47.02%.

In view of the above effects of tDCS on ERD, the use of a tDCS device may thus provide for a useful mechanism to assist in improving the classification of ERD based BCI applications for stroke rehabilitation -particularly where the ERD is lower than normal due to neurological damage. It may facilitate this by making ERDs more detectable. We suggest further tests with longer trials to verify the findings presented here.

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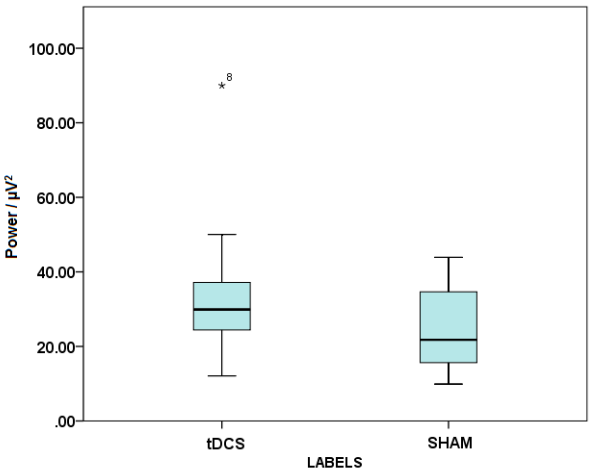

Fig. 3 Box and whisker plot of the step in ERD power for C3 pre- and post-motor image cue for the 10 participants. Plot on left represents spread for post tDCS and plot on the right for post sham (paired t-test: p=0.03)

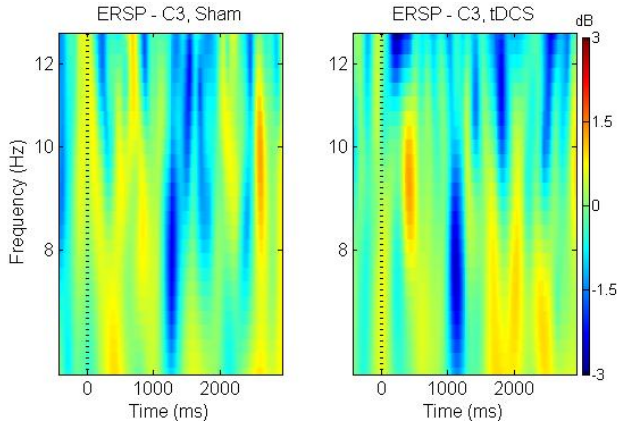

Fig. 4. Plot of ERSP averaged across ten participants. Sham (seen left) relative to tDCS (seen right) for C3.

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