Brain Stimulation and Brain Computer Interfacing

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In this workshop paper, we present two of our team's findings on the effect of brain electrical stimulation on BCI performance, reflecting a trend in neuro-engineering research. In many applications, BCI technology targets users with impaired neural activity and as such enhancement of such activity can be of great importance. We show that the application of transcranial direct current stimulation (tDCS) can significantly enhance an EEG potential (P300) which is used in BCI spellers. In addition, tDCS application also appears to improve working memory performance particularly relating to the recall of shapes.

Brain Computer Interface, Electrical Stimulation, EEG, Working Memory.

1. INTRODUCTION

Transcranial Direct Current Stimulation (tDCS) is a non-invasive brain stimulation technique which has recently benefitted from increased research interest. tDCS has been associated with improvements in cognitive functions (Dockery, et al., 2009; Sparing, et al., 2008), motor processing (Nietche et al., 2003), memory (Fregni et al., 2005) and learning in healthy brains (Flöel, et al., 2014). Potential effects of tDCS have also been investigated using range of patients, including those with neurodegenerative disease, movement disorders, epilepsy, and post-stroke language, attention, or executive deficits (Ferrucci, et al, 2008, Young, et al., 2013, Boggio, et al., 2012, You, et al., 2011). If shown to be reliable, tDCS has several advantages that render it attractive for clinical use in comparison to invasive stimulation. The technique is, as stated, non-invasive and elicits only a slight tingling under the electrodes (Matsumotoet al., 2017). Furthermore, tDCS can be applied continuously and safely for up to 20 minutes(Matsumoto et al., 2017). The device is also easy to use, small and relatively inexpensive. One area where non-invasive enhancement of neural function may be of benefit is Brain Computer Interfacing (BCI). The possible use of BCI for communication aids and in motor rehabilitation is considered in this paper. BCI based communication aids have been developed in the form of word spellers to help people, with severe motor disabilities, communicate with ease (Krusienski, et al.,2008, Salvaris, et al., 2009, Roula et al., 2012). The concept of a BCI speller is based on a system that enables a direct brain-to-character translation through what is referred to as the "oddball paradigm" (Fabiani et al, 1987). However, P300 systems have had limited practical applications, mostly because potential users may have reduced neural activity in one or multiple areas of the brain due to illness or damage. Partially as a consequence of this, very little research has looked at the effect of tDCS on P300 potentials and how tDCS may help facilitate the P300 response. Although not directly related, Antal (Antal, et al., 2004) reported measurable tDCS effects on Visual Evoked Potentials (VEP) with Lee and co-workers reporting measurable effects of tDCS on latency and amplitude (Lee, et al., 2014). In this paper we explore two experiments conducted by our team which appear to reveal that tDCS can have an important effect in enhancing cognitive responses that are crucial to BCI application (Izzidien et al., 2016; Ramaraju et al., 2018).

2. EFFECT OF TDCS ON P300 POTETIALS

2.1 Experimental setup

Eight healthy subjects (6 male and 2 female; aged 22 ± 3 years, all right-handed) participated in this study after giving written informed consent. No subject had any history of neurological disease or had been receiving any acute or chronic medication affecting the central nervous system. The University of South Wales Ethical Committee approved the investigation. The tDCS device (HDC-Stim HS0023L02-73, Newronika S.r.l in Figure 1a) with electrode size 5cm x5 cm was fitted with anode on left M1 and the cathode electrode over right supraorbital area. The tDCS consisted of 1.5mA of current applied for 15minutes interval.

Power measure		Sham				tDCS				ANOVA	
		Oz		Pz		Oz		Pz			
		Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Oz	Pz
P300	Relative	0.573	0.13	0.526	0.176	0.666	0.07	0.553	0.076	**0.103**	0.578
	Absolute	35.81	10.54	19.56	7.41	32.08	19.31	12.61	3.45	0.422	**0.000**

Table 1: Change in P300 response after tDCS application. Please note Oz and Pz refer to EEG recording channels. All the descriptive statistics and ANOVA was applied to the absolute and relative difference between the sham and placebo measurements. All the values are in μV^2.

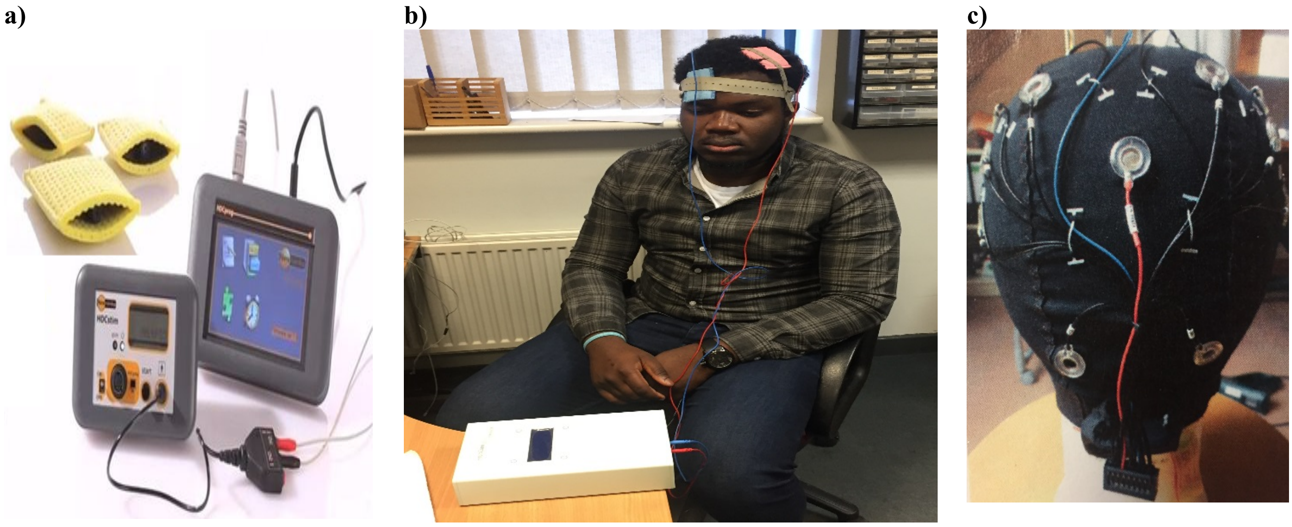

Figure 1: tDCS devices used in the research-a)Neuronika b)Neuroconn c) EasyCap EEG headset

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. P300 oddball speller, which contains all characters (A-Z), numbers from 0-9 and space bar was presented to the volunteer in a 6×6 matrix form. The participant was asked to sequentially “spell” the term "THE QUICK FOX JUMPS" by focusing on each of the nineteen (including spaces) characters inside the 6×6 matrix which they wanted to select. Two sequences were used to select a character. In a sequence, each row/column is intensified randomly. For each sequence, there are up to 12 intensifications (6 rows and 6 columns), and therefore a total of up 24 intensifications are used to evoke a response to a character. EEG signal was recorded using EasyCap GmbH(Figure 1c). The following measures were used to assess a P300 oddball response to intensified letters. Absolute as well as relative P300 power was measured and is shown in Table 1.

2.2 Results

Our results show that Anodal-tDCS (A-tDCS) has a significant effect on absolute P300 response. On average the absolute power across channel Pz for all subjects increased by 22% after A-tDCS when compared to sham whereas signal in Pz channel showed a 35% change in average absolute P300 signal.

3. EFFECT OF TDCS ON WORKING MEMORY

3.1 Experimental setup

Twenty male subjects (aged 30 ± 8 years) volunteered meeting the inclusion criteria (non-history of a neurological condition or had been receiving any acute or chronic medication affecting the central nervous system) signed informed consent. Both genders were invited to take part in this study, however, no female subjects volunteered.

A double-blinded, randomised, cross-over sham-controlled protocol was used for this study. Participants underwent two experimental tDCS sessions: one with sham A-tDCS (“sham”) and the other using real A-tDCS ("tDCS"). The anode was placed over L-DLPFC and the cathode was placed on the right supra-orbital area (SO) corresponding to F3-Fp2, as per the 10-20 international system for EEG electrode placement (Fregni et al., 2005). This montage is consistent with that used in previous research studies to investigate the effect of tDCS on working memory (WM) (Andrews et al., 2011; Fregni et al., 2005; Ohn et al., 2008).

Both the sham and tDCS sessions consisted of 15 minutes of stimulation (Izzidien et al., 2016). The sham session consisted of current ramping up to 1.5mA over a 8s period, followed by a 5s fade out and 870s without any significant stimulation (simply impedance control). The tDCS stimulation consisted of a current ramping up to 1.5mA over a 8s period, followed by continuous stimulation at 1.5mA. During the experiment, the impedance was always maintained less than the threshold value (12KOhm for 1.5mA) as per the recommendation of the manufacturers of the tDCS device (NeuroConn GmbH-Figure 1b). The stimulation used in this study was an offline stimulation.

3.2 Working Memory Measurement Protocol

WM tests were applied separately, with the choice of which test was to be presented first being determined by random number generation (Microsoft Excel). A single sham or tDCS session included two WM test runs (one letters and one shapes). For the duration of the experiment, subjects sat in an armless chair, facing a computer monitor placed approximately at 0.7m in front of them at the eye level (180^0) with their right index finger on the right arrow of the keyboard. Before the start of the experiment, the subjects were briefed on how the 2-back test for WM would be conducted and were given the opportunity to rehearse both the letters and shapes paradigms.

In the letters WM test, subjects were shown English alphabet letters (A-L) one at a time (each appearing for 2s), presented in a randomised order.

A blank screen was presented for 1.5s between images (letters or shapes depending on the test). The subjects were instructed to press either the right mouse button if they considered the images were identical, or doing nothing if not (Figure 2).

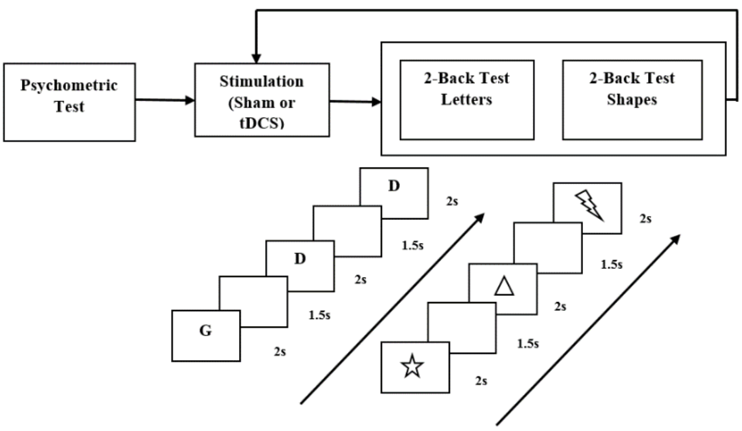

Figure 2: Summary of experimental protocol

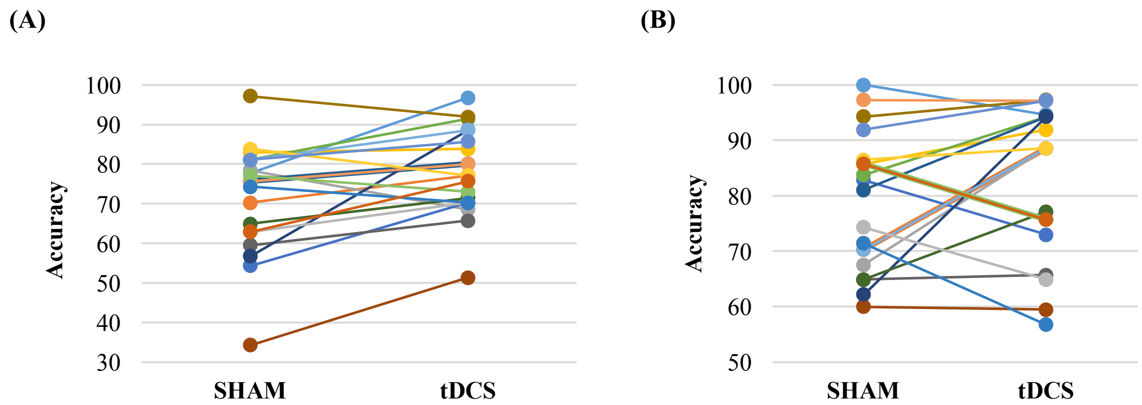

Figure 3: Individual transition plots of accuracy for each of the 20 subjects across sham and tDCS groups in case of a) shapes and b) letters.

In the case of the *2*-back test with shapes (slanted S, oval, rectangle, mirrored tick mark, equilateral triangle, right angled triangle, rhombus, pentagon, 4-sided star, 6-sided star, thunderbolt, inverted jig-saw), the presentation procedure was the same as for the letters protocol.

3.2 Results

The WM accuracies using both letters and shapes were compared between sham and tDCS sessions (summarised in Figure 4 and Figure 5). Eighty percent of the subjects exhibited an increase in their accuracy on the shapes *n-back* test after the application of tDCS, compared to only 60% when using the letters-stimulus. The nature of the study, (a cross-over sham-controlled trial design) a repeated measures ANOVA was indicated. a significant change in *n back* test accuracy between tDCS and Sham [$F(1,76,)= 5.43$, p=0.02] as well as par-significant change across memory stimuli types [$F(1,76)= 3.81$, p=0.05] and insignificant interaction between stimuli and stimulation [$F(1,76)=0.276$, p=0.6]. These results indicate the significant effect of tDCS stimulation on working memory accuracy irrespective of the type of stimuli used and also indicate a significant difference in outcome between the stimuli, regardless of the type of stimulation used. To further understand the relationship, the relative degree of change (effect size) between sham and tDCS groups across shapes and letters memory stimuli types was determined using Cohen's *d*-test. This test produced *d*-values of 0.98 and 0.38 for shapes and letters, respectively.

4. CONCLUSION

The results of this study may help the development of neuro-rehabilitation methods targeting the parietal lobe. A heightening of the P300 response using A-tDCS may help also improve the accuracy of P300 based oddball paradigm spelling devices for neurologically impaired subjects. These spellers, although being shown to work in principle, have had limited practical application partly because potential users often have reduced neural activity in one or multiple areas of the brain due to illness or damage. A rehabilitation regime of A-tDCS stimulation, used in conjunction with oddball paradigm spellers might help improve their usability, hence benefiting their users by allowing them to communicate more easily. These users primarily include sufferers from conditions such as Motor Neuron Disease (MND), stroke and traumatic brain injury victims.

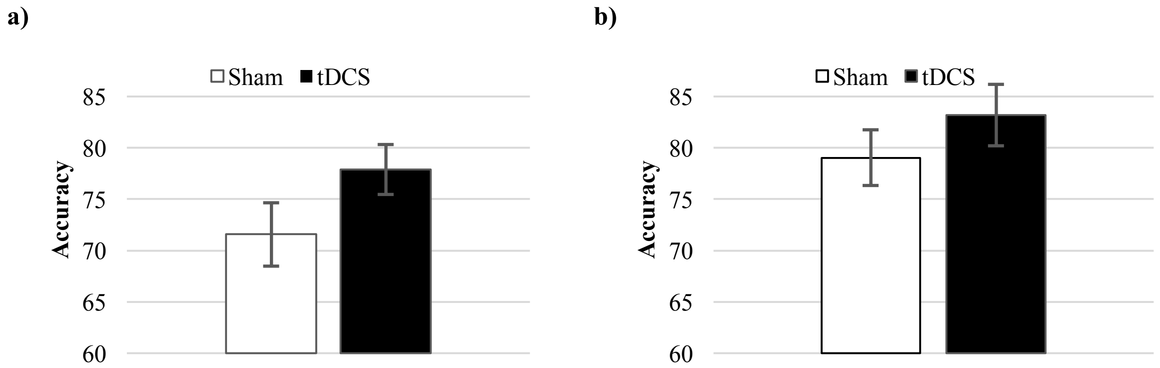

Figure 4: The average accuracy across sham and tDCS groups (n=20) for a) shapes and b) letters. Error bars used represent standard error of mean (S.E.M).

Furthermore, this paper has presented results showing the effect of A-tDCS on working memory to be dependent on memory stimuli used. In particular, a significant A-tDCS effect was found using shapes based WM stimuli while none was found for letter-based ones. This finding may have relevance to understanding of the selective effect of tDCS and its interaction with varied modes of brain activity in particular the ones used in brain computer interfaces.

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