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Transcranial direct current stimulation of the motor cortex in waking resting state induces motor imagery

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ABSTRACT

This study investigates if anodal and cathodal transcranial direct current stimulation (tDCS) of areas above the motor cortex (C3) influences spontaneous motor imagery experienced in the waking resting state. A randomized triple-blinded design was used, combining neurophysiological techniques with tools of quantitative mentation report analysis from cognitive linguistics. The results indicate that while spontaneous motor imagery rarely occurs under sham stimulation, general and athletic motor imagery (classified as athletic disciplines), is induced by anodal tDCS. This insight may have implications beyond basic consciousness research. Motor imagery and corresponding motor cortical activation have been shown to benefit later motor performance. Electrophysiological manipulations of motor imagery could in the long run be used for rehabilitative tDCS protocols benefitting temporarily immobile clinical patients who cannot perform specific motor imagery tasks – such as dementia patients, infants with developmental and motor disorders, and coma patients.

1. Introduction

Motor imagery forms an integral part of human consciousness. Such mental representations of movement without analogous body movement (Guillot & Collet, 2005) occur regularly and spontaneously, especially in states with naturally high motor cortical activation, such as rapid eye movement (REM) sleep (Desseilles, Dang-Vu, Sterpenich, & Schwartz, 2011; Dresler et al., 2011; Porte & Hobson, 1996; Speth, Frenzel, & Voss, 2013), and have been associated with motor learning and rehearsal (Hobson, 2009; Walker, Brakefield, Morgan, Hobson, & Stickgold, 2002). Motor simulation tasks can also be purposefully used in waking to benefit specific motor performances (Arora et al., 2011; Driskell, Copper, & Moran, 1994; Jackson, Lafleur, Malouin, Richards, & Doyon, 2006; Meister et al., 2004; Schuster et al., 2011).

Studies revealing the strong relationship between motor simulations and motor system activation, functioning independently of motor performance (Abbruzzese, Assini, Buccolieri, Marchese, & Trompetto, 1999; Bonnet, Decety, Jeannerod, & Requin, 1997; Decety, 1996; Fadiga et al., 1999; Jeannerod, 1995, 2001; Porro et al., 1996; Schnitzler, Salenius, Salmelin, Jousmäki, & Hari, 1997) have given rise to the hope that motor imagery will provide a backdoor to the motor system after impairments (Jackson, Lafleur, Malouin, Richards, & Doyon, 2001; Lehéricy et al., 2004; Sharma, Pomeroy, & Baron, 2006). To this end, motor imagery has been shown in neurofeedback task paradigms to increase regional cortical activation: long-term effects of increased activation of motor areas involving neural circuitries associated with motor skill learning can last up to

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several days (Kober et al., 2014; Yoo, Lee, O'Leary, Panych, & Jolesz, 2008). We can assume that motor imagery and motor system activation form a functional unit that, if activated in the resting state, serves the purpose of training motor performance.

Transcranial direct current stimulation (tDCS) offers a way to manipulate cortical excitability. As it is non-invasive, has limited side effects, and is more comfortable and less irritating for participants than other brain stimulation techniques, tDCS can benefit the study of spontaneous brain activity and consciousness. Anodal tDC stimulation has been shown to increase the excitability of the motor cortex, while cathodal stimulation decreases its excitability (Nitsche & Paulus, 2000). TDCS can thus influence motor performance (Pavlova, Kuo, Nitsche, & Borg, 2014), and facilitate motor learning (Prichard, Weiller, Fritsch, & Reis, 2014). While the effects of tDCS in conjunction with motor imagery have been studied before (Foerster et al., 2013; Quartarone et al., 2004), those studies used motor imagery as an independent variable by actively asking participants to imagine motor movements, and measured effects only on dependent physiological variables. To our knowledge, however, no study reports the direct influence of tDCS of motor areas on phenomenology, such as the experience of motor imagery.

The AIM model of consciousness proposes that the motor imagery perceived in REM sleep dreams is a direct result of higher motor cortical activation (Hobson, 2009; Hobson, Pace-Schott, & Stickgold, 2000). TDCS may also enable us to manipulate motor cortical excitability in order to test whether there is a strong causal relationship between activation of the motor system and spontaneous motor imagery as it occurs in REM sleep dreaming, or through the use of mental motor rehearsal techniques in waking.

The present study investigates if anodal and cathodal tDCS of the motor cortex elevates the degree of spontaneous motor imagery in the waking resting state. We expect anodal, but not cathodal tDCS, to induce spontaneous motor imagery compared with sham stimulation. Such tDC stimulation protocols could in the long run benefit especially such temporarily immobile clinical patients who cannot perform specific motor imagery tasks, such as mentally disabled patients, dementia patients, patients with psychological disorders, infants with developmental and motor disorders, and coma patients.

2. Method

To study motor imagery in the waking resting state, along with the possibility of its enhancement, mentations are investigated as conceived in a no-task-no-response setting (Vaitl et al., 2005) under anodal, cathodal, and sham stimulation. Motor imagery was measured with a quantitative linguistic tool: *motor agency analysis*. Agency analysis has been used in previous studies, and has been shown to be a reliable tool (Speth, Speth, & Harley, 2015; Speth et al., 2013). Study participants were computer randomized to the stimulation conditions. The current study is triple-blind in so far as neither the participant delivering the report, nor the investigator recording it, or the raters analysing it, knew the stimulation condition. The study was approved by the University Research Ethics Committee (UREC) of the University of Dundee, and conducted in the Dundee Sleep and Consciousness Laboratory.

2.1. Participants

Participants were male and female undergraduate volunteers. Participants were issued an information sheet on the experimental procedure, and were told that they would be asked to answer a series of questions towards the end of the testing. No further details were given on the specific purpose of the experiment in order to prevent participants from engaging in metacognitions and the planning of their verbal report or other interview responses during the mentation period. Participants were assured however that they would be able to refuse answers, without further explanation, at any time. Participants were informed about the possibility that they would feel a slight tingling sensation during the tDC stimulation. Participants with diagnoses of epilepsy or severe migraines would have been excluded from the study, along with participants who reported a history of allergic skin reactions. Written informed consent was obtained from all participants prior to the experiment.

2.2. Questionnaires

A short open-answer questionnaire assessed participants' age, gender, native language, nationality, education, medication, as well as the time of last caffeine consumption, the general level of caffeine consumption, physical exercise on the day of testing, amount of physical exercise per week, and meditation experience. Handedness was tested with a short version of the Edinburgh handedness inventory (EHI-short; Veale, 2014).

2.3. Experimental design

The experiment was conducted in a low-stimulus environment. After the investigator had attached the tDCS and EEG electrodes, participants were asked to rest in a reclining chair while a simple EEG recording of their brain would be conducted. Participants were asked to keep their eyes closed and their body movements to a minimum in order to promote the accuracy of the EEG. Participants were informed that the investigator would be in an adjacent room and return after