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Research Report

Corticomotor excitability induced by anodal transcranial direct current stimulation with and without non-exhaustive movement

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ABSTRACT

We investigated whether anodal transcranial direct current stimulation (tDCS) applied to the motor cortex during non-exhaustive active or passive movements enhances corticomotor excitability after tDCS or whether it reduces post-exercise depression (PED) after non-exhaustive active or passive movements if PED was observed without tDCS. Nine healthy subjects participated in this study. Anodal tDCS with a current of 2 mA was applied to the left scalp over the primary motor area. All subjects underwent the following five interventions: tDCS delivered for 10 min during relaxation (tDCS condition) and repetitive voluntary and passive finger abduction–adduction movements, each performed without and with tDCS for 10 min (active condition, tDCS+active condition, passive condition, tDCS+passive condition). The active movements were performed at 10% maximum voluntary contraction. Motor evoked potentials (MEPs) were recorded from the right first dorsal interosseus muscle before the intervention (pre-intervention) and 2 and 10 min after the intervention (post-2 min and post-10 min, respectively). Under the tDCS condition, the MEP amplitudes at post-2 and -10 min were significantly increased compared with those before the intervention. Under the active, passive, and tDCS+active conditions, the MEP amplitudes at post-2 min were significantly decreased compared with those before the interventions. Under the tDCS+passive condition, the MEP amplitude remained unchanged. These results demonstrated that anodal tDCS did not reduce PED after active movements but after passive movements and that the anodal tDCS effects were highly dependent on the state of the subject during stimulation.

Abbreviations: tDCS, Transcranial direct current stimulation; MEP, Motor evoked potential; TMS, Transcranial magnetic stimulation; PED, Post-exercise depression; PEF, Post-exercise facilitation; FDI, First dorsal interosseus muscle; EMG, Electromyography; IEMG, Integrated electromyography; MVC, Maximum voluntary contraction

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1. Introduction

Transcranial direct current stimulation (tDCS) is a non-invasive technique for modulating brain excitability (Nitsche and Paulus, 2000; Nitsche et al., 2003b). It is well known that the nature of these modulations depends on tDCS polarity. Corticomotor excitability is increased by anodal tDCS, whereas it is decreased by cathodal tDCS (Nitsche and Paulus, 2000). Several studies have investigated changes in motor evoked potentials (MEPs) elicited by transcranial magnetic stimulation (TMS) and have shown that tDCS application to the motor cortex modulates cortical output (Nitsche and Paulus, 2000; Nitsche et al., 2003a, 2003b). In addition, functional neuroimaging studies have demonstrated changes in corticomotor excitability elicited by tDCS (Baudewig et al., 2001; Jang et al., 2009; Lang et al., 2005). The effects evolve during tDCS and remain for 1 h after stimulation if tDCS is applied for >10 min (Nitsche and Paulus, 2000; Nitsche et al., 2003b, 2005). As suggested by several studies, the effect of tDCS depends on a neuronal de- or hyperpolarization of membrane potential changes (Bindman et al., 1964) and modulation of N-methyl-D-aspartate receptor efficacy (Liebetanz et al., 2002; Nitsche et al., 2003a, 2004). Many investigators have indicated that tDCS enhances the beneficial effects of motor learning (Kantak et al., 2012; Nitsche et al., 2003c), motor function (Boggio et al., 2006; Hummel et al., 2005), fatigue resistance of the target muscle (Cogiamanian et al., 2007), and reaction time or muscle strength (Hummel et al., 2006) in healthy volunteers or patients with neurological disorders.

TMS of the human motor cortex is used to examine the changes in corticomotor excitability, which occurs after voluntary muscle contraction (Balbi et al., 2002; Chye et al., 2010; Sacco et al., 1997; Samii et al., 1996). Brasil-Neto et al. (1993) and Samii et al. (1996) reported a decrease in the amplitude of MEP evoked by TMS after exhaustive exercise with muscle fatigue; this phenomenon was called post-exercise depression (PED). Brasil-Neto et al. (1993) observed that PED is induced after exhaustive exercise; however, it has also been shown to be induced after non-exhaustive exercise (McDonnell and Ridding, 2006; Teo et al., 2012; Zanette et al., 1995). Potential mechanisms for PED include long-term depression, decreased neurotransmitter levels, decreased excitability of intracortical glutamatergic networks, or increased excitability of inhibitory GABAergic networks (Zanette et al., 1995; Samii et al., 1996; Teo et al., 2012). Because spinal reflexes do not change, PED may be caused by intracortical mechanisms. From these reports, we concluded that muscle fatigue and PED are different phenomena. On the other hand, the amplitude of MEP increased after non-exhaustive exercise (Balbi et al., 2002; Brasil-Neto et al., 1999; Pridmore et al., 2001); this phenomenon was called post-exercise facilitation (PEF). A potential mechanism for PEF is long-term potentiation (Samii et al., 1996). Several studies have confirmed this phenomenon and have shown that PED is often preceded by a short initial PEF (Brasil-Neto et al., 1994; Liepert et al., 1996; McKay et al., 1995). Recently, Teo et al. (2012) reported that PED was observed after a 10 s of non-exhaustive finger movement and persisted for 8 min after movement.

Corticomotor excitability has recently been shown to change with not only voluntary movements but also passive movements (Lewis et al., 2001; Edwards et al., 2002, 2004; Coxon et al., 2005; Mace et al., 2008). Coxon et al. (2005) have found that MEP amplitudes are facilitated during passive muscle shortening and are suppressed during passive muscle lengthening. Mace et al. (2008) have found that training involving passive movement for 60 min results in prolonged increase in corticospinal excitability.

tDCS has been used to improve motor functions of the paretic limb in patients with stroke (Edwards et al., 2009; Hummel et al., 2005, 2006). Therefore, when tDCS is combined with other neurorehabilitative modalities, investigating whether corticomotor excitability can be enhanced is useful. Kwon and Jang (2011) used functional magnetic resonance imaging in their study and suggested that the cortical activity induced by anodal tDCS application to the motor cortex during motor tasks was higher than that induced without tDCS application during the same motor task. In contrast, Antal et al. (2007) reported that the corticomotor excitability observed when anodal tDCS was applied to the motor cortex during motor tasks was lower than that observed when anodal tDCS was applied during the rest condition. However, they did not indicate whether their motor task without tDCS application enhanced or suppressed corticomotor excitability.

The purpose of this study was to determine whether application of anodal tDCS during motor exercise affects the tDCS-induced modulation of corticomotor excitability. We hypothesized that anodal tDCS application to the motor cortex during finger movements would affect the tDCS-induced modulation of corticomotor excitability and reduce PED after finger movements if PED is observed after the finger movements without tDCS.

2. Results

Fig. 1 shows the superimposed MEP waveforms for all subjects and Table 1 shows the mean MEP amplitude induced by TMS under all conditions.

Two-way repeated measures analysis of variance revealed significant main effects of both CONDITION ($F_{(4,\ 32)}=6.859$, $p<0.01$) and TIME ($F_{(2,\ 16)}=8.700$, $p<0.01$). Further, the CONDITION × TIME interaction was significant ($F_{(3.087,\ 24.699)}=4.753$, $p<0.01$). Post-hoc analyses demonstrated non-significant differences among the MEP amplitudes elicited by each condition before the intervention (pre-intervention; $p>0.1$). The MEP amplitudes elicited 2 min after the intervention (post-2 min) in the tDCS condition were significantly larger than those elicited in the active condition and the tDCS+active condition ($p<0.01$). The MEP amplitudes that were elicited at post-2 min in the tDCS+passive condition were significantly larger than those elicited in the active condition ($p<0.01$) and the tDCS+active condition ($p<0.05$). The MEP amplitudes elicited 10 min after the intervention (post-10 min) in the tDCS condition and the tDCS+passive condition were larger than those elicited in the active condition ($p<0.05$) (Fig. 2).