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Letter to the Editor

# Intentional switches between coordination patterns are faster following anodal-tDCS applied over the supplementary motor area

*Dear Editor:*

The supplementary motor area (SMA) plays a critical role in the regulation of in-phase (IP) and anti-phase (AP) coordination [1,2], as it is thought to simultaneously code the actions of each limb, as well as their temporal sequencing [3]. Previously [4], we showed that applying offline anodal-tDCS for 10 minutes improved participants' ability to maintain AP coordination at higher movement frequencies, which consequently delayed the spontaneous AP-to-IP switch; however, anodal-tDCS did not affect the more stable IP coordination. The SMA has been identified as a key neural correlate of spontaneous switching [2,5], yet its role during intentional switching is less clear, with some recent evidence suggesting that the SMA is more active during intentional IP-to-AP switches compared to the reverse direction [6]. Here, we used transcranial direct current stimulation (tDCS) to investigate the role of the SMA in mediating the interaction between pattern stability and intentional switching. In a randomized, double-blind crossover design, ten right-handed participants ($M_{age}$ = 24.7 years, SD = 7.25; 6 males) completed two separate bimanual coordination testing sessions where either anodal-tDCS or sham-tDCS was applied between pre- and post-tDCS testing blocks. The experiment was approved by the Research Ethics Board at the University of Ottawa and written informed consent was obtained from all participants before the start of the experiment.

Trials began with participants performing synchronous coordination patterns with the forearms requiring either IP (simultaneous supination and pronation) or AP (alternating supination and pronation) cyclical movements at different movement frequencies (1.75, 2.0, or 2.25 Hz) paced by an auditory stimulus (1000 Hz, 25 ms). Trials lasted 18 s and once on each trial, an auditory switch cue (650 Hz, 150 ms) was presented randomly between 7 and 12 s, which prompted participants to intentionally switch between patterns as quickly as possible and maintain the new pattern for the remainder of the trial (i.e., IP-to-AP or vice versa). Testing sessions were separated by at least 48 hours and both sessions consisted of pre- and post-tDCS blocks with 18 trials in each. These 18 trials included nine trials in each switch direction with three trials performed at each of the three different pacing speeds. tDCS was delivered through two scalp electrodes using a Dupel iontophoresis constant current delivery device (Empi) and stimulation order was counterbalanced. The active electrode (7.8 $cm^2$) was saturated with sterile saline and positioned 1.8 cm anterior to Cz (International 10–20 system) while the return electrode (39 $cm^2$) was placed above the eyebrows in the center of the forehead. For anodal-tDCS, a direct current of 1 mA was applied for 10 minutes which resulted in a current density of 0.128 $mA/cm^2$ at the active electrode. For the sham-tDCS, the stimulator was only powered on while ramping up to 1 mA (~15 s) and was then immediately shut off without the participant's awareness (see Ref. [4] for greater detail regarding tDCS protocol and data reduction procedures).

Switching time is a key behavioral measure of the interaction between intention and intrinsic dynamics [6] and was defined as the time that elapsed between the point where relative phase first deviated from its mean previous mode and the achievement of the new coordination pattern [i.e., ±20° of the intended pattern for at least three consecutive cycles;7]. Switching time (Fig. 1) for AP-to-IP was faster than switching from IP-to-AP (F [1,9] = 100.86, $P < 0.001$, $\eta^2_p = 0.92$), and switching time decreased as movement frequency increased (F [1,9] = 39.42, $P < 0.001$, $\eta^2_p = 0.81$). These findings replicate those of past research demonstrating that switching behavior is tightly coupled to pattern stability and movement frequency [6,7]. Most importantly, there was a significant tDCS x Block interaction (F [1,9] = 7.09, $P = 0.026$, $\eta^2_p = 0.44$) and Tukey's post-hoc comparisons revealed switching times in the post-Anodal block were significantly faster than those in the pre-Anodal ($P = 0.007$, $d = 1.97$), pre-Sham ($P = 0.007$, $d = 1.94$), and the post-Sham ($P = 0.019$, $d = 1.56$) blocks, all of which did not differ significantly from each other. This novel and noteworthy finding confirms that the interaction between intention and intrinsic dynamics can be modulated with anodal-tDCS over the SMA, as participants were able to discontinue their initial coordination mode and switch into the alternative mode significantly faster following anodal-tDCS, irrespective of switch direction. Anodal-tDCS resulted in a facilitation of switching time by 159.9, 160.6, and 134.1 ms compared to the pre-anodal, pre-sham, and post-sham blocks, respectively and the large effect sizes indicate that these are robust results.

The facilitative effects of anodal-tDCS on intentional switching between coordination patterns is consistent with, and extends our previous work showing a similar effect for spontaneous switching behavior [4]. Although the number of participants in the current study was small (N = 10), post-test performance following anodal-tDCS showed a significant decrease in switching time, suggesting a consistent effect between participants. However, the single location of tDCS application does not allow us to conclusively confirm that the observed effect was due to SMA facilitation, as the tDCS may have increased activation in other areas as well [1]. Despite not having a control stimulation site, we believe the most likely explanation for the observed positive effect of anodal-tDCS in the current study is SMA facilitation given the theoretical role the SMA plays in bimanual coordination [3] along with fMRI and TMS evidence for its involvement in these tasks [1,2,5,6]. Our data does allow us to

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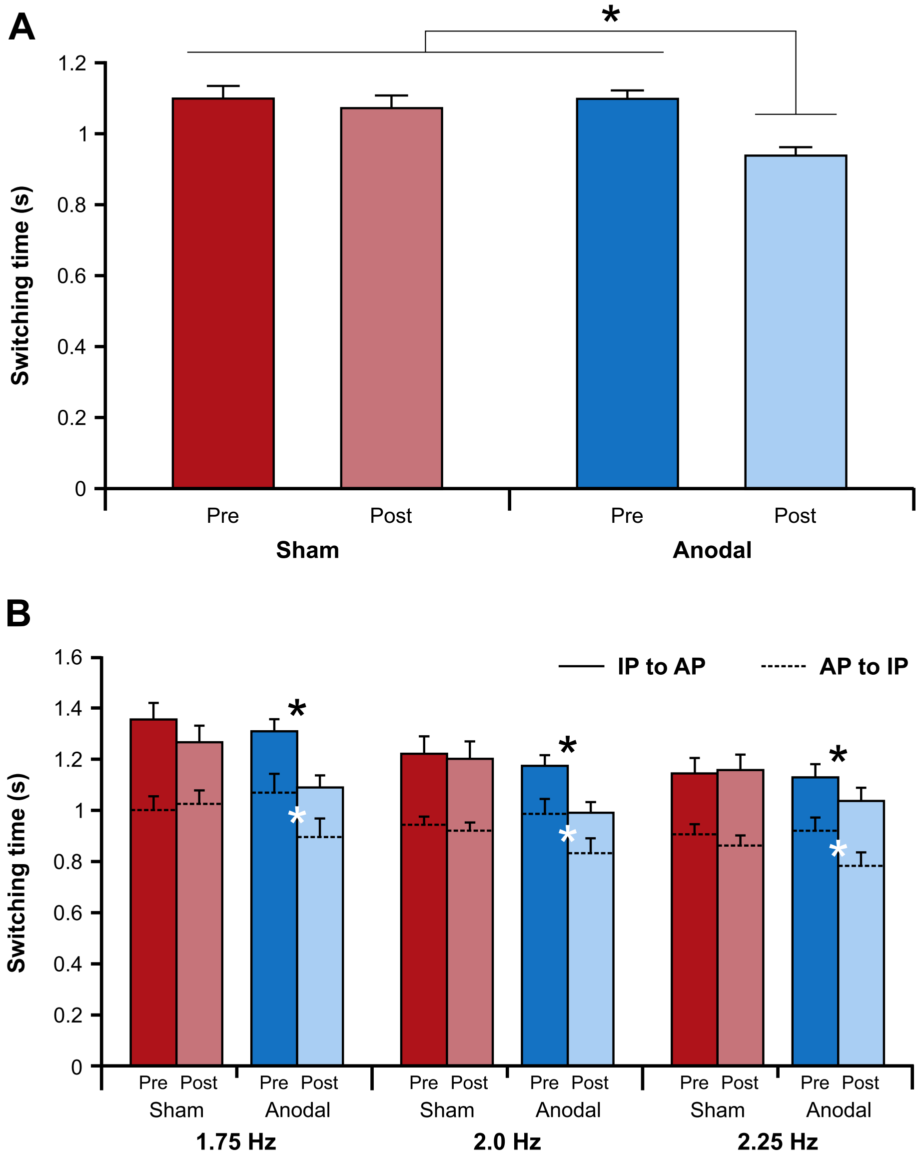

**Fig. 1.** Behavioral results for switching time (s). (**A**) Grand means for the significant interaction of tDCS and testing block that clearly show a significant reduction in the post-anodal block compared to all other blocks. (**B**) Grand means are plotted as a function of switch direction (IP to AP [solid line]; AP to IP [dashed line]), tDCS (Sham [red]; Anodal [blue]), and testing block (Pre [dark]; Post [light]) for the three different movement frequencies. Note that AP to IP switches were always faster than IP to AP switches (dashed line always below the corresponding solid line). As expected, sham-tDCS did not affect switching times for either direction; however, switching times were significantly shortened following anodal-tDCS for all movement frequencies and for both switch directions (denoted by black and white asterisks for IP to AP and AP to IP switches, respectively). Error bars for both figures represent within-subject 95% confidence intervals. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

rule out other factors such as practice effects or pre-test differences. Practice effects were not seen in the sham condition, as switching time in the post-sham block showed a modest and non-significant decrease relative to the pre-sham block (26.5 ms), as compared to the substantial and significant reduction in the pre-to-post anodal tDCS trials (159.9 ms). Similarly, the lack of difference in pre-sham and pre-anodal blocks (<1 ms) confirms that pre-test performance was a similar level prior to stimulation. Collectively, these results provide convincing evidence that switching time was reduced primarily by a performance enhancing effect following anodal-tDCS [8].

In conclusion, the present results show that anodal-tDCS applied over the region of the SMA can have a beneficial impact on the interaction between intention and intrinsic dynamics; thus, providing additional evidence that the SMA plays an important role in optimal integration during bimanual coordination. While our results reveal short-term benefits of anodal-tDCS for bimanual coordination, it may be worthwhile to investigate whether these effects can persist longer with repeated stimulation protocols. Extending these short-term performance gains following anodal-tDCS over longer periods could have significant implications for optimizing rehabilitation protocols for clinical populations, such as Parkinson's disease patients [9,10], who suffer from bimanual coordination deficits; this in turn could benefit activities of daily living, independence, and quality of life.

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