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Task switching ability is compromised after cross-hemispheric tDCS over the parietal cortex

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Abstract:

***Background/Aims**: One of the components of working memory is the ability to respond to unexpected demands and rapidly shifting attention between tasks. Previous studies have used transcranial direct current stimulation (tDCS) in order to modulate task and set shifting ability over the prefrontal cortex. However, set shifting/task switching ability requires a left-lateralized fronto-parietal network. In this study, we aimed to assess if delivering active cross-hemispheric tDCS over the parietal cortex - right anodal/-left-cathodal (pRA-LC) and right cathodal/-left anodal (pRC-LA), as compared to sham tDCS, is able to modulate task switching ability in healthy volunteers.*

***Methods:** A total of 17 college students who volunteered (age: 21.65 ± 4.42, 14 females) participated in this pilot study in which the effects of three different single session tDCS conditions over the parietal cortex on task switching ability were assessed.*

***Results:** There were significant differences in terms of switch costs F (2,28) = 4,01, p < .05 dependent on stimulation. Bonferroni pairwise comparisons showed that the Response Time (RT) of the Switch Cost increased significantly (M = 102.84, SD = 18.24) for the pRA-LC condition, when compared with the sham condition (M = 49.44, SD = 17.84) (p = .03, d=2.96)*

***Conclusions:** The results of this study highlight the importance of studying the role of the parietal cortex in task switching ability. An activity shift towards the right parietal hemisphere (i.e., pRA-LC) impaired task switching performance, which is consistent with the role of the left parietal cortex on endogenous preparation and adjustment of goal directed behaviors. Future studies should focus on exploring the electrophysiological and neuroimaging correlates associated with the tDCS effects over the parietal, as well as exploring the usefulness of multi-site stimulation.*

***Keywords:** tDCS, task switching, parietal cortex*

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INTRODUCTION

The ability to respond to unexpected demands and rapidly shift attention between tasks (i.e., rules or sets) is a core component of executive functioning (Chan, Koval, Johnston, & Everling, 2017). This task switching ability that changes attentional focus and guides the selection of responses accordingly, is a subcomponent of a broader concept known as "cognitive flexibility" (Leber, Turk-Browne, & Chun, 2008; Sali, Courtney, & Yantis, 2016). The neuromodulation of task switching ability has attracted attention in the last years, specially by the use of non-invasive brain stimulation techniques. Previous studies have used transcranial direct current stimulation (tDCS) in order to modulate task and set shifting ability. For instance, in the first study that used

tDCS to successfully modulate set shifting, we showed that 30 min of 1mA over the left prefrontal cortex (PFC) or the left M1 increased set shifting performance (Leite, Carvalho, Fregni, & Gonçalves, 2011). Moreover, if 2 mA tDCS is applied bilaterally to the PFC, task switching performance can be modulated in two different types of task switching (i.e. letter/digit naming and vowel-consonant/parity tasks) (Leite, Carvalho, Fregni, Boggio, & Gonçalves, 2013). Furthermore, other types of non-invasive brain stimulation techniques which use random noise have also shown that task switching ability can be modulated (Morales-Quezada et al., 2016). Despite the fact that tDCS is able to modulate set/task switching ability, most of the studies so far have been focusing on the PFC. However, imaging studies suggest that during task switching, there is an involvement of a left-lateralized fronto-parietal network (Brass & Von Cramon, 2002; Liston, Matalon, Hare, Davidson, & Casey, 2006; Worringer et al., 2019).

In this sense, it is possible that cognitive flexibility may be modulated using different cortical targets, such as the parietal cortex. For instance, tDCS over the parietal cortex, when compared to tDCS over the PFC, was able to decrease false recognition rate and bias in an item and source discrimination task (Pergolizzi & Chua, 2016). Moreover, anodal tDCS over the left parietal cortex was able to increase attention to a focus word in a sentence (Minamoto et al., 2014), and high-density tDCS over the parietal cortex was able to increase speed of retrieval of correct word-picture pairs (Perceval, Martin, Copland, Laine, & Meinzer, 2017). Thus, it is of upmost importance to study other cortical targets for the modulation of cognitive functions, as they may help to understand the role of specific regions on broader network modulation.

Considering that tDCS has effects on the parietal cortex and that task switching also relies on the parietal cortex, in this study we aimed to assess if delivering cross-hemispheric tDCS over the parietal cortex - right anodal-left-cathodal (pRA-LC) and right cathodal-left anodal (pRC-LA), as compared to sham tDCS, is able to modulate task switching ability in a set of healthy volunteers.

METHOD

Participants

A total of 17 healthy college students (age: 21.65 ± 4.42, 14 females) volunteered for this pilot study. This study was performed with non-clinical participants. All participants were right-handed (Edinburgh Handedness Inventory ≥ 80), with normal or corrected-to-normal visual acuity. Participants were excluded if they had present or past history of any unstable medical condition that may have precluded adequate and safe testing, or if they had any contraindication for the use of tDCS. Participants were advised to avoid caffeine, alcohol or cigarettes in the day of the experiment, and procedures were postponed if they reported insufficient sleep. Written informed consent was sought from all the participants. All the study procedures were performed in accordance with the Declaration of Helsinki and approved by the local ethics committee.

Overall Design

Participants were randomized to receive all 3 tDCS conditions in a counterbalanced manner: 2 active (Right Anodal – Left Cathodal (pRA-LC) and Left Anodal – Right Cathodal (pLA - RC) over the parietal cortex) and one sham over the parietal cortex, with an intersession interval of at least 72h. This was performed in order to reduce the inter-individual variability effects of tDCS among subjects. Each 45 min session consisted of a baseline assessment of several conditions that may constitute a side effect of tDCS using several Visual Analogue Scales (VAS) and then participants performed the task-switching task. For this task, participants received 3 min of tDCS prior to beginning task performance, in order to allow for the stabilization of the tDCS effects in the brain. Then they performed the task-switching task for the remaining 27 min. Afterwards, the participants responded to the VAS after tDCS, in order to compare to the values that they had reported previously.

Main task

In this task, participants were presented with a cue that remained on screen for 500ms, prior to the appearance of the target. The target consisted of a number inside a colored circle (either red or green) that was presented for 2500ms. If the color presented was green, participants had to press the "Z" key if the number presented on screen was odd or the "M" key if the number presented on screen was even. If the color of the circle was red, participants should follow the magnitude rule by pressing "Z" key if the number presented was >5 and "M" key if the number presented was <5, using the left or right index respectively. After a key press from participants, the target was replaced by another fixator for 500ms. If two consecutive trials were of the same

color, there was no rule change (parity or magnitude), however if in two consecutive trials there was a change in color, there was a rule change, and that constituted repeat and switch trials, respectively. The order in which trials were presented to participants was fully randomized, only restricted by the switch/repeat condition.

There were a total of 160 trials, in 80 of those trials there was no rule change – repeat trials, while for the remaining 80, there was a rule switch. In order to minimize effects due to learning due to S-R color mappings, there were two different tasks in which color rule mapping was inverted, which were presented randomly to participants **(Figure 1 A).**

Transcranial Direct Current Stimulation

tDCS was applied through rubber electrodes slotted in 35 cm2 saline-soaked sponges, using an Eldith DC Stimulator Plus (Neuroconn, Germany). Electrodes were placed over the P3 and P4 electrode sites according to the 10-20 international system (Jasper, 1958) **(see figure 1 B)**. There was at least a 6 cm distance between the anode and the cathode. A current density of 0.057 mA/cm2 was applied for a total duration of 30 min, and 15s ramp up and 15s ramp down for the active condition. The sham tDCS was applied following the procedure of active tDCS, and the duration of the stimulation was 15s.

Outcomes

The main outcomes of this study are Response Time (RT) and Accuracy (ACC). Both outcomes are assessed by comparison to the previous one. In other words, the time each participant took to respond (RT), and if they were accurate (ACC) or not was assessed in comparison to the previous trial, considering that in two consecutive

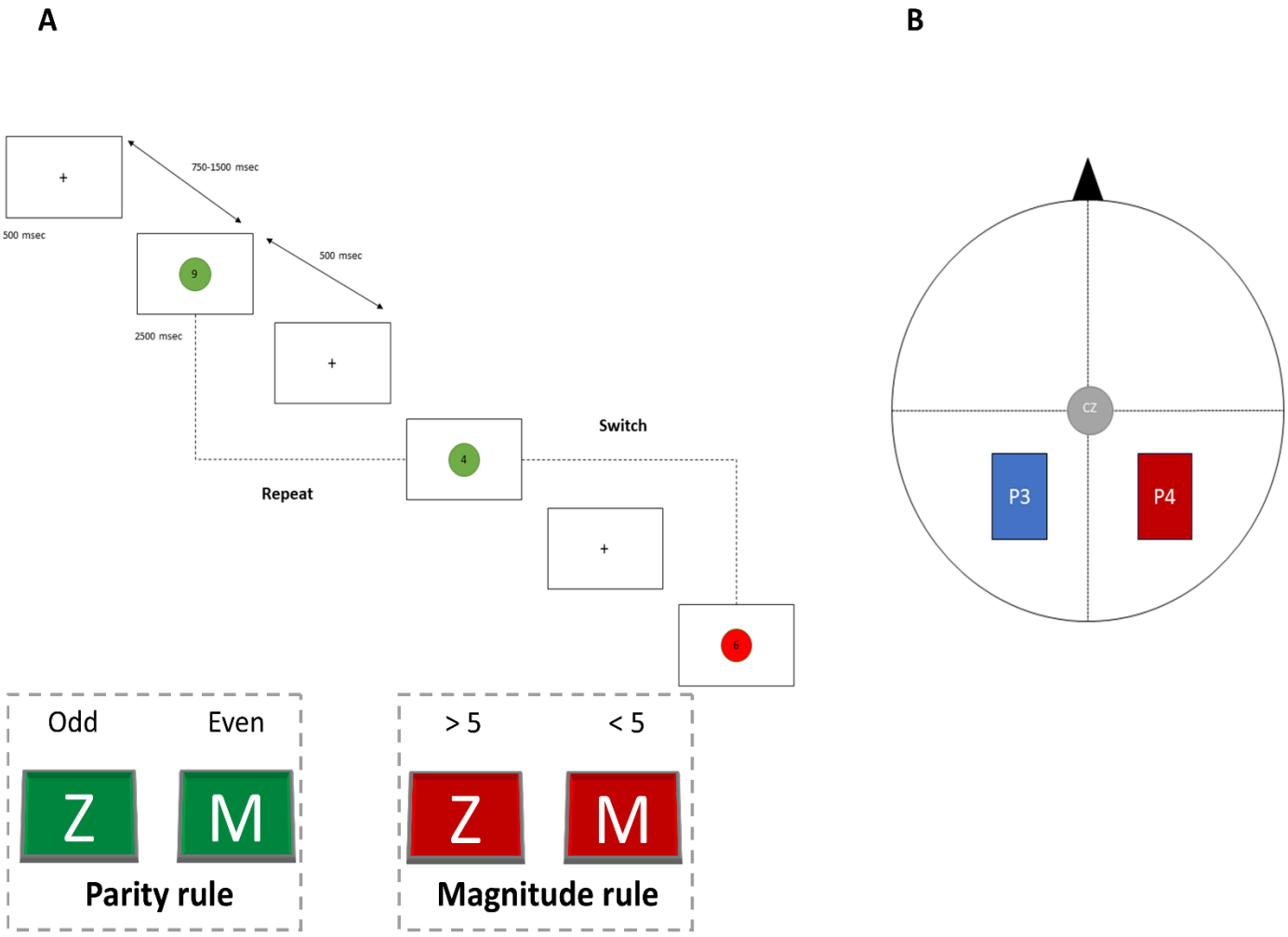

Figure 1 – A. Schematic Representation of the task switching task used in this study. There were a total of two tasks versions, in which the color mappings were reversed. B -schematic representation of the electrode montage used in this experiment.

trials, the rule to perform the task could change (i.e., switch), or not (i.e. repeat). For the response time, only correct answers were assessed.

Data Analysis

For the primary outcome, switch cost indexes for response time (RT) were calculated subtracting the mean RT of correct responses from the switch trials from the mean RT from the repeat trials. Switch costs for accuracy were calculated subtracting the accuracy from responses to switch trials (i.e., rule changed) from responses to repeat ones (i.e. same rule applied).

Two one-way repeated measures ANOVAs with three levels (RA-LC; RC-LA and sham tDCS) for switch cost accuracy and response time were performed. If there were significant main effects of tDCS, then ANOVAs were followed-up with Bonferroni adjusted pairwise comparisons.

Paired sample t-tests were used to evaluate differences in symptoms from pre to post tDCS as assessed by a 10-point Visual Analogue Scales (VAS). Alpha values were set at .05.

RESULTS

tDCS effect on Switch Cost Response Time (RT)

There were significant differences in terms of switch costs F (2,28) = 4,01, p < .05 dependent on stimulation. Bonferroni pairwise comparisons showed that the RT of the switch cost increased significantly (M = 102.84, SD = 18.24) for the RA-LC condition, when compared with the sham condition (M = 49.44, SD = 17.84) (p = .03, d=2.96) **(Figure 2)**

tDCS effects on Switch Cost Accuracy

No significant differences were found between conditions F (2,28) = 0.1, p >.05 **(Figure 2)**

Side Effects

Participants reported a significant increase in discomfort (t (16) = -3,32, p = .004, d=1.04) and headache (t (16) = -3.86, p = .001, d=1.02) following pRA-LC stimulation. A significant increase in discomfort (t (16) = -4.02, p < .001, d=1.09) and itching (t (16) = -4.61, p < .001, d=1.11) after pLA-RC stimulation, and a significant increase in headache (t (16) = -3.22, p = .005, d=0.72) after the sham condition. However, these symptoms were mild, not reaching on average 4 points in a 10-point scale.

DISCUSSION

In the present study, we tested the effects of single session cross-hemispheric tDCS over the parietal cortex on task switching performance in healthy volunteers.
The present study showed that pRA-LC tDCS, over the parietal cortex, increased switch cost in terms of response time when comparing to sham tDCS, which is consistent with a previous study in which RA-LC over the prefrontal cortex impaired task switching performance in a vowel/consonant task (Leite et al., 2013). Thus, suggesting different roles (i.e. LA-RC increased performance, whereas LC-RA increased accuracy) for each of the PFC hemispheres and their critical interdependence in task switching performance. This is somewhat different from the effects of tDCS over the parietal cortex, at least by using a cross-hemispheric

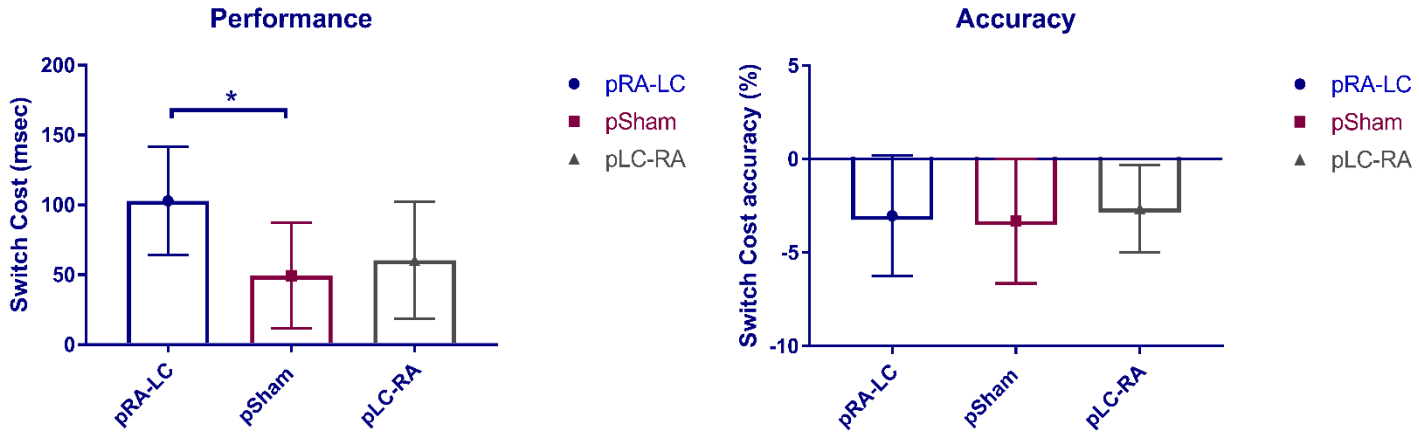

Figure 2. Results from this response time and accuracy switch cost (Switch-repeat trials). Bars represent the 95% CI based on the Standard Deviation

tDCS montage, namely because in the present study, there were no effects of parietal cortex stimulation in terms of switch cost accuracy. Moreover, the main effect in the present study seems to be an impairment of task switching performance, induced by pRA-LC tDCS.

Interestingly enough, a recent study applied cross-hemispheric tDCS over the prefrontal and parietal cortex, and showed that task switching performance increased only when it was required to overcome a previous inhibition in order to switch back to a recently inhibited task (Sdoia, Zivi, & Ferlazzo, 2020). As task switching depends on an extensive brain network, it is not surprising to consider that specific regions may be also responsible for specific functions that underlie the general cognitive ability. For instance, Ravizza and Carter (2008) suggested that rule switching is more dependent on the prefrontal cortex, while perceptual shifting is more dependent on the parietal cortex. If this hypothesis is true, then a task such as the one presented in this study could rely more on the PFC. Moreover, previous research already showed that both the PFC and the parietal cortex are important for the performance of several cognitive functions. In addition, the modulation of the parietal cortex may have a detrimental effect in a task that was traditionally associated to the PFC. For instance, it has been shown that Transcranial Magnetic Stimulation (TMS) over the parietal cortex impairs response inhibition in a stop signal task (Osada et al., 2019). As tDCS effects are simultaneously focal as well as widespread across the brain (Lang et al., 2005), it is possible that tDCS-induced modulation of the parietal cortex actually induced a detrimental effect because it downregulated the activity of the PFC.

Moreover, if rule switching would be a task that was more dependent on the PFC, one would expect no effect on task performance of parietal tDCS, or a similar, detrimental effect, regardless of polarity. This is not the case in this study. Our results are consistent with the assumption that task switching may be a more left-lateralized function, especially during endogenous response preparation (Sohn, Ursu, Anderson, Stenger, & Carter, 2000). It is possible that the RA-LC tDCS condition, induced a hemispheric shift towards the right hemisphere, which may have interfered with the endogenous preparation required to successfully perform the switch. Surprisingly, a shift of activity towards the left hemisphere did not produce any significant results in terms of task performance. However, activity shift towards one of the hemispheres does not always induce an effect, such as we previously demonstrated in a proactive inhibition task, in which tDCS over the right inferior frontal gyrus induced an increase in inhibitory control, whereas shifting the interhemispheric imbalance to the right hemisphere did not (Leite et al., 2017).

Concerning side effects of tDCS, they were either absent or mild, thus being similar to what is already established in the literature (Bikson et al., 2016; Brunoni et al., 2011) .

However, this study is not without limitations. The first one is that in order to fully understand the present results, neuroimaging measures will be required. That would allow us to understand the psychophysiological interaction among and between brain networks during task performance, and how they were modulated by tDCS. Secondly, tDCS over other brain regions should be tested, in order to fully understand the role of the parietal cortex in task switching. Finally, perceptual changes could not be adequately tested, as the tasks required a switch based on a rule.

Future studies should address these limitations and also explore the combination of multi-site tDCS in order to modulate cognitive flexibility, as well as to include neurophysiological and neuroimaging methods, to fully understand the impact of tDCS in the brain, rather than relying solely on behavioral indicators.

In sum, the results from this pilot study highlight the importance of studying the role of the parietal cortex in terms of task switching, among other functions. An activity shift towards the right parietal hemisphere (i.e., RA-LC) impaired task switching performance, which is consistent with the role of the left parietal cortex on endogenous preparation and adjustment of goal directed behaviors. Future studies should focus on exploring the electrophysiological and neuroimaging correlates associated with the tDCS effects over the parietal and prefrontal cortex, as well as exploring the usefulness of multi-site stimulation.

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Conflict of interest and financial disclosure

The authors declare no personal or financial conflicts of interest. JL and SC are part of the editorial team of the PPCRJ. Therefore, they excuse themselves from the peer-review process and followed the journal guidelines for peer reviewing when an editor co-authors a manuscript. They did not influence the editorial process and final publication decision.

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