Saudi Journal of Biological Sciences 26 (2019) 1956–1960

Contents lists available at ScienceDirect

Saudi Journal of Biological Sciences

journal homepage: www.sciencedirect.com

Original article

Modulation of human visuospatial attention analysis by transcranial direct current stimulation (tDCS) in the line bisection performance

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ARTICLE INFO

Article history:
Received 8 May 2019
Revised 6 June 2019
Accepted 12 June 2019
Available online 12 June 2019

Keywords:
Pseudoneglect
Posterior parietal cortice
Rebalance
Modulating effect

ABSTRACT

The general population shows physiologic biases in the line bisection performance for visuospatial attention, almost to the left known as pseudoneglect. Previous studies have shown that tDCS affects visuospatial attention in line bisection. This research applies tDCS over left posterior parietal cortice (P3) or right posterior parietal cortice (P4) to explore the effect on pseudoneglect. Subjects randomly were divided into five groups by stimulation distribution: (i) P3-anodal (P3A), (ii) P3-cathodal (P3C), (iii) P4-anodal (P4A), (iv) P4-cathodal (P4C), (v) sham. Participants respectively finished the post-tDCS line-bisection assignment (lines on the left/right side of the monitor (LL/LR), and lines in the center of the monitor (LC)) the same as the pre-tDCS task over the session (P3A, P3C, P4A, P4C and sham) tDCS condition. The principal findings were that P3A tDCS reduced the leftward shift in the horizontal line bisection task, as well as P4C tDCS reduced the leftward shift in LL. Sham stimulation as well as P3C and P4A stimulation didn't have systematic improvements in the line bisection tasks. Therefore, an activation–orientation model of pseudoneglect is corroborated by these findings. Activation of intact structures in the rebalance of left and right parietal cortex might impose modulating effects on tDCS.

1. Introduction

Many studies focusing on lesion and neuroimaging have observed that the cerebral hemisphere to the right dominates visuospatial attention process, and neurologically intact individuals showed a behavioral preference to the left visual area, the properties defined as pseudoneglect that had been repeatedly discovered (Bowers and Heilman, 1980; Desimone and Duncan, 1995; Charles et al., 2007; Siman-Tov et al., 2007; Kashiwagi et al., 2018). Compared to clinical neglect, pseudoneglect was a less extreme phenomenon. It referred to a leftward bias in physical line bisection performance in terms of the activated right hemisphere(Corbetta and Shulman, 2002, Corbetta et al., 2008, Corbetta and Shulman, 2011; Sparing et al., 2009; Newman et al., 2013), judgements of length, luminance and numerosity (Zuanazzi and Cattaneo, 2017; Benwell et al., 2015; Vangkilde et al., 2012; Schenkenberg et al., 1980; Nicholls et al., 1999; Sprague, 1966).

The activation in visualspatial orientation of pseudoneglect revealed that spatial attention preferred to the mirror side in terms of the stimulated hemisphere (Nobre and Rohenkohl, 2014; Moran and Desimone, 1985). In revised activation orientation models, the concept of pseudoneglect and neglect were substituted and manifested by mirror model for hemisphere in neural activation. The left visual side was assumed to reduce activation for depletion of right hemisphere neural network capacity and connectivity, as visuospatial attention task being in stimulation (Martinez-Trujillo and Treue, 2004; Heise et al., 2014). These accounts therefore suggested that the right lateralized ventral network preference to visualspatial activation orientation induced a leftward shift in horizontal line bisection task (Corbetta and Shulman, 2011; Iyer et al., 2005; Rushmore et al., 2013).

In order to evaluate allocentric spatial judgements, the physical line bisection experiment as a frequently applied task was originally delivered by Schenkenberg et al. (1980). Healthy participants taken in horizontal line bisection tasks demonstrated an outweighing effect on the left field in the perceived midpoint of the line (Benwell et al., 2013, 2014; Jewell and McCourt, 2000; Doricchi et al., 2005; Bultitude and Davies, 2006). This observation was

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Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.sjbs.2019.06.007

quite opposite to the experiment results participated by right-hemispheric neglect patients in brain lesions (Halligan et al., 1990; Voyer et al., 2012). Besides, it was interesting to find that the different level details of lateralized bias participants experience in terms of visual processing, both participants with neurological diseases or no neurological diseases included, was contingent upon dynamic changes, such as the different degree of attention load and time-on-task/arousal (Bonato et al., 2010; Fimm et al., 2006; Perez et al., 2008, 2009), and the other non-spatial attention factors (Manly et al., 2005; Peers et al., 2006; Matthias et al., 2010; Newman et al., 2013; Vuilleumier et al., 2008). Another famous task, inheriting and adjusting from previous ones (Schenkenberg et al., 1980), required patients to bisect 20 horizontal lines distributed over an entire page (Lezak et al., 2004). In this experiment, it not only observed a typical leftward shif tendency, but also demonstrated the relevance to the relative position (left, middle, right) of an offsetting line at the midpoint of the page.

As a noinvasive neural modulation, tDCS stimulation is not only portable, but also costs much less and thus may be suitable to external regulation of spatial attention (Fan et al., 2009; Loftus and Nicholls, 2012; Vuilleumier et al., 2008). To our knowledge, two methods both cathodal stimulation over the left PPC and anodal stimulation over the right PPC included may be combined with possible effect on decreasing pseudoneglect. During the greyscales task, Loftus and Nicholls (2012) recently applied tDCS stimulation over the left posterior parietal cortex (P3) and the right posterior parietal cortex (P4) to modulate visualspatial attention, as a well result, anodal electrode over P3 increased the neuronal activement for equalising asymmetric interhemispheric neural activation balance and reduces pseudoneglect, but canodal electrode over P4 (generally decreases neuronal excitability) did no significant effect on the left bias tendency for the task and made no impact on pseudoneglect. In addition, Sparing et al. (2009) used tDCS to alter visual spatial attention in line bisection performance for healthy and/or neurological neglect participants. In the control group with healthy participants, anodal electrode stimulation over the cerebral hemisphere made better visual performance in the contralateral parietal cortices, as well as cathodal electrode stimulation over the cerebral hemisphere induced better visual behaviour in the ipsi-lateral parietal cortices. Taken anodal tDCS over the lesioned PPC as well as cathodal tDCS over the unlesioned PPC, the neurological neglect patients had a better line bisection performance reducing left neglect. These findings propose that tDCS over the neural cortics exerts modulating effects on visual attention by rebalancing the interhemispheric activation asymmetry.

However, it remains unknown whether tDCS of the left PPC/ right PPC could decrease pseudoneglect under different conditions in line bisection task. In this case, we devised an innovative test of the variation model proposed by Schenkenberg et al. (1980) and Lezak et al. (2004) applying tDCS to modulate the visualspatial attention. Here, Participants are asked to point and click the centre of the line with respect to the viewer's trunk midline (left, middle, right) on the computing monitor by the mouse. We discussed not only the reproductive measurement of tDCS stimulation over hemispheric cortics, but also the degree of anodal/cathodal tDCS effects over left/right PPC on different offsetting line bisection tasks.

2. Materials and methods

2.1. Subjects

Forty right-handed (Oldfield, 1971) undergraduate students with no neurological lesion, were major participants in this experiment (with age ranging from 25 to 40 years). All subjects' vision were normal or corrected to normal. We got an approval by the University human ethics committee and participants were consent of this experiment statement proposed.

2.2. Transcranial direct current stimulation (tDCS)

tDCS containing anode and canode electrodes is a constant current stimulator(neuro Conn GmbH, Germany). In this study, a directing current of 1 mA (current density = 0.03 mA/cm^2, total charge = 34 C/cm^2) was constantly used for 15 min in accordance with the safety guideline (Lyer et al., 2005). At the beginning or end of tDCS, let the current go through a high/ low slope and keep it for 30s.

The stimulation paradigm used in this experiment consisted mainly of five types: for the left PPC stimulation group (positive/ negative stimulation), the left PPC stimulation group with a P3 located electrode (according to the international 10-20 system). The comparative one is in FP1 (avoiding current flow through the contralateral hemisphere), then the placements of electrodes were interchanged, so the anode/cathode stimulation was reversed at the same position; for the right PPC stimulation group (positive/ negative stimulation), the right PPC stimulation group with a P4 located electrode (according to the international 10-20 system). The comparative one is in the FP2, then the placements of electrodes were interchanged, so the anode/cathode stimulation was reversed at the same position; when the sham stimulation was performed, we put the first electrode in P3 (in a accordance with the internatioal 10-20 system), the comparative electrode is in the FP2. In the same tDCS condition ,but the stimulator was sustained only for 30s.

Subjects remained awake at rest during the stimulation process. Following tDCS, the stimulator was turned off, the stimulating electrodes were removed, the motion state after stimulation was observed, and the impedance of each lead was examined, especially the ipsilateral side of the stimulating electrode (FP1 or FP2). After the examination, subjects were required to repeat pre-tDCS task that was the exactly same sequence of completion as before the stimulation, to avoid the error caused by the sequence of the experimental tasks.

2.3. Line bisection task

Participants were randomly assigned to 5 stimulation groups: (i) P3-anodal (P3A), (ii) P3-cathodal (P3C), (iii) P4-anodal (P4A), (iv) P4-cathodal (P4C), (v) sham. Participants respectively completed all the line-bisection tasks one by one: (i) tDCS pre-stimulation tasks, (ii) cathode/anode/sham-stimulation, and (iii) tDCS post-stimulus tasks. The task before stimulation is the same as the task after stimulation over the session (P3A, P3C, P4A, P4C and sham) tDCS condition.

Participants were required to sit on a height-adjustable seat with their eyes looking straight into the center of the screen, so that the eyes were 70 cm from the screen (27″), and the midline at eyeheight was coincident with the center of the screen. The specifics of this task (based on the classic line bisection task of Schenkenberg et al. (1980) is showed in Fig. 1. Subjects performed three different tasks during the experiment: (15 trials per block, center of the line relative to the midline of the screen): 1 block of lines located on the left of the screen (LL), and 1 block of lines located on the right of the test screen (LR), and 1 block of lines located at centerlines of the screen (LC). Each task block consists of 15 trials with a trial interval of 1.2 s. During each task, the red line stimuli presented on a green background, subjects divided the horizontal line on the computer monitor, and used the left mouse button as a small black transistor to click on the center of the line. The signaling the start of a new trial was as soon as the

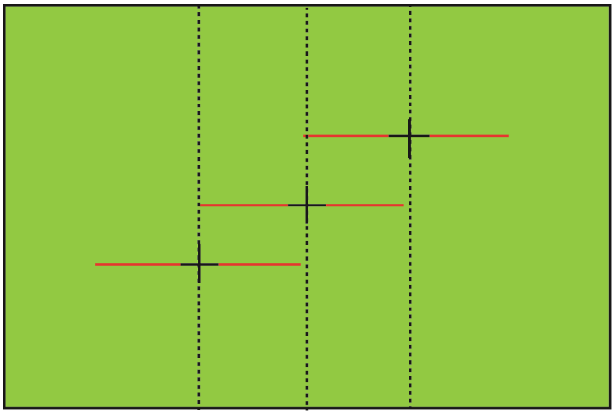

Fig. 1. Line bisection performance applied in the current research (lines located on the left of the screen (LL)), lines located on the right of the screen (LR), and lines located in the middle of the screen (LC)).

time at the centre of the line fixated. The deviation from the center of the line was translated into the offset ratio referring to the screen length pixels. In coding stage, we coded leftward deviations negative and rightward deviations positive.

Prior to the formal experiment, participants were asked to be familiar with the entire stimulation process. During the experiment, the subject was asked to concentrate on the line stimulation on the screen, and press the mouse under the right index finger as soon as possible to perform the line bisection task.

3. Results

All participants were resistant to tDCS stimulation without any adverse side effects. Few participants felt an itching sensation under both electrodes at the beginning of tDCS. For each trial, participants bisected horizontal lines as a result of 'left', 'center' and 'right' responses, respectively. Analysis of the bias between the left responses and the right responses,we use the left one minus the right part, the subtraction will be showed in the form of percentage. Finally we get the result. The scores representing bias range from −100% to +100% indicated a preference to the left or right relative to the center of screen, respectively.

In this study, statistical analysis was carried out by Friedman test method for differently marked lines: (i) divided into 5 groups according to 5 experimental conditions (P3A, P3C, P4A, P4C, SHAM); (ii) each block was divided into 3 different positions (LL, LC and LR) relative to the center of the screen. The Friedman test method were used to analyzes the statistical differences between the different five groups of different stimulation conditions and the three line-level tasks of the relative display center position. To analyze thoroughly, we also applied paired comparisons with two-tailed Wilcoxon-tests to dual lines with paired experimental conditions to determine whether the bias has significant difference from the sham condition. The significance level $\alpha < 0.05$ was statistically significant.

Across the five experimental stimulation conditions (P3A, P3C, P4A, P4C, sham) with respect to the lines (LL, LC, LR) of pre-tDCS, no significant difference in bias statistics was observed by Friedman-test ($x^2(4) = 1.222$, $P > 0.05$, n.s.), but for post-tDCS, significant difference in bias statistics was shown by Friedman-test ($x^2(4) = 11.809$, $P < 0.05$). And for post stimulation, paired comparisons with Wilcoxon-tests (see Fig. 2) were conducted with results of significant differences in test tasks between sham and P3 athodal tDCS ($z = -3.198$, $P < 0.05$), as well as sham and P4 cathodal tDCS ($z = -2.421$, $P < 0.05$).

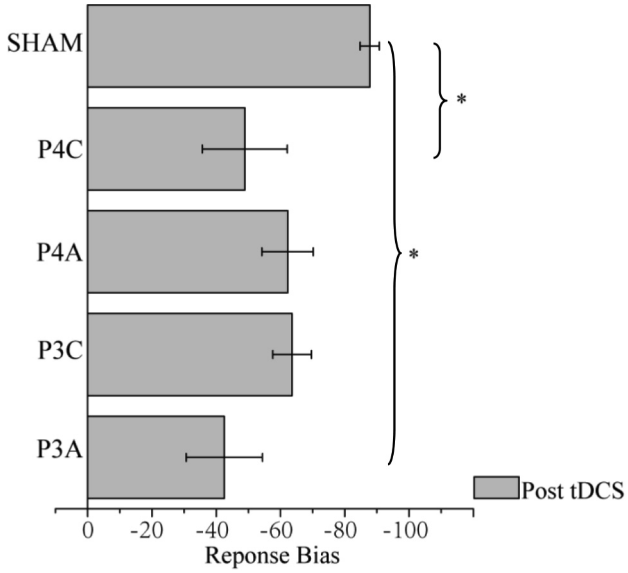

Fig. 2. In the line-bisection tasks, left/right offsetting data relative to the center was negative/positive; Paired comparisons by Wilcoxon-test between P3A, P3C, P4A, P4C stimulation and SHAM stimulation were revealed within each graph. Statistical significance with respect to the reduction of the leftbias was shown during P3A and P4C stimulation compared to the sham condition.

In order to more thoroughly analyze the interaction between the five stimulation conditions (P3A, P3C, P4A, P4C, SHAM) relative to the different positions of the screen center (left, center, right), the data for each group (P3 athodal stimulation, P3 cathodal stimulation, P4 athodal stimulation, P4 cathodal stimulation, sham stimulation) were analyzed separately to determine whether tDCS made separately different bias with respect to different lines bisection (LL, LC, LR) among the five experimental conditions (see Fig. 3). As the result, no significant performance on deviation in line bisec-

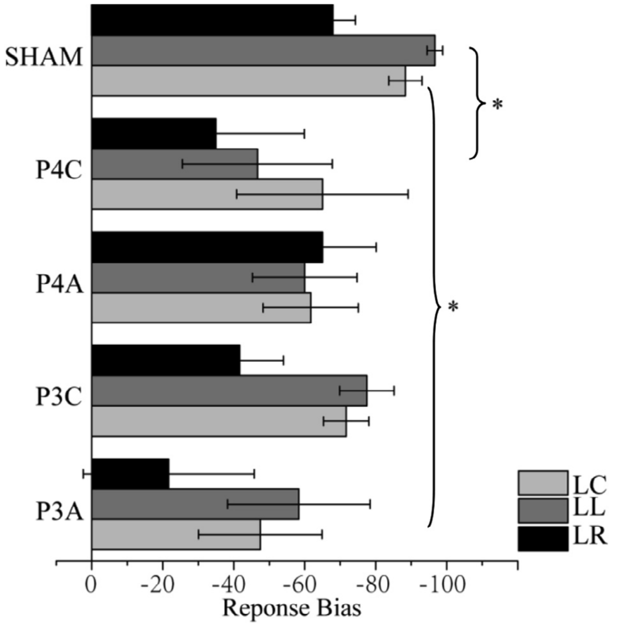

Fig. 3. Effect of tDCS (P3A, P3C, P4A, P4C) on lines (LL, LC, LR). Negative/positive values represented left/right offsetting data relative to the center. Statistical significance with respect to the reduction of the leftbias was shown during P3A for LC-lines performances and P4C stimulation for LL-lines performances as compared to the sham condition.

tion tasks was shown during post-tDCS condition for lines located in the middle of the monitor ($x^2(4) = 6.883$, $P > 0.05$, n.s.) and located on the right of the monitor ($x^2(4) = 3.477$, $P > 0.05$, n.s.). However, there was a significant deviation with respect to the correlation of the experimental condition by Friedman-tests ($x^2(4) = 9.273$, $P < 0.05$). In the LC-lines bisection tasks, Wilcoxon-tests of paired comparisons yielded a significant effect of bias for the P3 athodal tDCS condition group ($z = -2.207$, $P < 0.05$); In the LL-lines bisection tasks, Wilcoxon-tests of paired comparisons yielded a significant difference of bias for the P4 athodal tDCS condition group ($z = -2.032$, $P < 0.05$) as well as P4 cathodal tDCS condition group ($z = -2.207$, $P < 0.05$). No expressive effect on left deviation for any other line-bisection tasks with respect to different stimulation conditions had been demonstrated.

4. Discussion

The main focus in this research is to investigate neural mechanisms with respect to tDCS modulating effects on bias in visual spatial task performance for neurologically normal subjects among the five experimental conditions, separately for the five groups (P3A, P3C, P4A, P4C, sham) and separately for the LL, LC and LR lines. We investigated that P3A tDCS reduced the leftward shift in horizontal line bisection, as well as P4C tDCS reduced the leftward shift in horizontal left offsetting line bisection. Not only sham stimulation, but also P3C and P4A stimulation caused no significant effect on the left deviation in all bisected lines. As different offsetting lines (LL, LC, LR) considered separately, we detected significant behavioural changes in line bisection task for subjects conducted by means of different stimulation. The interpretation for these three issues were as followings.

Firstly, it is recommended that a rebalance of the interparietal activation is modulated by applying the left PPC with anodal stimulation. In good accordance with previous neurological researches (Kinsbourne, 1970; Duncan, 1984, Duncan and Humphreys, 1989; Siman-Tov et al., 2007; Bonato et al., 2010), tDCS applied over posterior parietal cortices rebalanced activation asymmetry by the means of inhibiting right hemispheric activity, consequently, pseudoneglect of the healthy participants is expressly modulated in the horizontal line bisection. Based on this line of reasoning, P3 cathodal tDCS makes no effect on pseudoneglect for healthy subjects, but P3 athodal tDCS apparently decreases the levels of pseudoneglect in the present study because the increasement of the activation in the left posterior parietal cortices. These findings are consistent with asymmetrical distribution to the left hemisphere, however, we did not successfully demonstrate the specifical modulation by tDCS in terms of the activation asymmetry for neural mechanisms.

Secondly, it is necessary to explain why the P4 cathodal tDCS reduced the leftward shift in horizontal left offsetting line bisection. It is well-known that patients suffering from severe neglect tend to show an attentional deviation to the right parietal lobe in visual spatial line bisection. Comparing to other stimulation conditions, P4 cathodal tDCS alleviated more right bias in line-bisection performance located in the middle of the monitor according the studies using horizontal line task (Schenkenberg et al., 1980; Jewell and McCourt, 2000; Loftus and Nicholls, 2012). In the control group of healthy participants, Sparing et al. (2009) discovered that the performance of visual detection is subject to the cathodal effect and further inferred that cathodal tDCS seems to affect greyscales task performance. Also consistent with this interpretation, our present study suggests that P4 cathodal tDCS enhances excitability of the right PPC with rebalancing activation asymmetry between hemispheres. To sum it up, maybe the decreased right hemispheric activation observed during prism adaptation share similar performance with P3 athodal tDCS to affect asymmetric hemispheric activation and pseudoneglect.

Finally, issue concerning the role of sham stimulation, as well as P3C and P4A stimulation lead to no systematic improvements in bisected-lines regarding all horizontal bisection tasks (see Fig. 2). The cathodal tDCS stimulation didn't make a sense,only inhibited a bit of activation over the left PPC and the athodal tDCS stimulatioon inceased a bit of facilitory over the right PPC. So without the enough asymetrically distributed attention to the left hemispace. The pseudoneglect was not decreased. Line-bisection behavior in the task with the first 30 s initial direct current flow of sham stimulation over left posterior parietal cortex suggest that lower duration and intensity of the stimulation reducing pseudoneglect for healthy participants is unsufficient. Regarding all bisection lines (see Fig. 3), this illustration could also contribute to the reasons why no significant difference in line bisection task was achieved among left-cathodal tDCS, right-athodal tDCS and sham stimulation. The interpretations for this might be are unclear. For the further study of visuospatial attention modulation, higher duration and intensity of P3C stimulation or P4A stimulation in line bisection task would be an interesting question.

Consequently, tDCS as a sensory stimulation technique of two different polarities (athodal and cathodal) induces asymmetrical activations in both cerebral hemispheres system (Bundesen, 1990; Bundesen et al., 2005). tDCS expressly improved a leftward bias in line-bisection perfromances for healthy participants, because this may be capable to modulate the behaviour in congnitive tasks.

5. Conclusion

In conclusion, the modulation impacts of tDCS might be induced by activation of intact hemisphere in the rebalance of left and right parietal cortex. Future studies with a greater cognitive component should focus on the potentials of repetitive tDCS in achieving improvements in a much longer form in visuospatial pseudoneglect differentially affected by anodal or cathodal tDCS.

Acknowledgements

The work was financially supported by a grant from the National Project of China (No. 2017ZX10304403), and we are grateful to those who participated in the study.

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