Putting Focus on Transcranial Direct Current Stimulation in Language Production Studies

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Previous language production studies targeting the inferior frontal and superior temporal gyrus using anodal tDCS have provided mixed results. Part of this heterogeneity may be explained by limited target region focality of conventionally used electrode montages. In this simulation study, the focality of conventionally used and alternative bipolar electrode montages was examined. Specifically, electric field distributions of anodal tDCS targeting IFG and STG in conventional setups (anodal electrode over IFG/STG, reference electrode over right supraorbital region) were compared to a number of alternative electrode montages. Conventional montages showed maximum field strengths that next to the target region included additional neighbouring regions. By contrast, adjustments in electrode size and placement improved focality of anodal tDCS. Thus, the heterogeneity of findings of language production studies deploying conventional tDCS montages may in part be explained by diffuse electric field distributions. Alternative montages improve focality and may yield more unequivocal results.

Keywords: transcranial direct current stimulation; language production; focality; simulations

Transcranial direct current stimulation (tDCS) is administered over the left inferior frontal gyrus (IFG) and posterior superior temporal gyrus (STG) to examine the role of these regions in language production in healthy volunteers. However, results of tDCS on language production performance have been subject to a significant degree of variability. For example, a number of studies reported a beneficial effect of anodal tDCS reflected in higher verbal fluency scores or shorter response times in picture naming tasks (Cattaneo, Pisoni, & Papagno, 2011; Fertonani, Rosini, Cotelli, Rossini, & Miniussi, 2010; Holland et al., 2011; Meinzer et al., 2012; Sparing, Dafotakis, Meister, Thirugnanasambandam, & Fink, 2008; Vannorsdall et al., 2012), while others found no effect (Cerruti & Schlaug, 2009; Ehlis, Haeussinger, Gastel, Fallgatter, & Plewnia, 2016; Henseler, Mädebach, Kotz, & Jescheniak, 2014; Vannorsdall et al., 2016; Westwood, Olson, Miall, Nappo, & Romani, 2017). Thus, even though tDCS may be effective in establishing effects on language processes, the heterogeneous results illustrate the difficulties associated with tDCS in anticipating the direction of its behavioral effects. Issues concerning the spatial resolution of the induced electric field are considered to be one of the important contributors to diversity of tDCS-related effects. The vast majority of studies routinely placed one electrode over either the IFG or STG and the return electrode over the right supraorbital region (rSO, e.g. Cattaneo et al., 2011; Ehlis et al., 2016; Fiori, Cipollari, Caltagirone, & Marangolo, 2014; Pisoni, Cerciello, Cattaneo, & Papagno, 2017; Pisoni, Papagno, & Cattaneo, 2012; Westwood et al., 2017).[1] Even though these montages have demonstrated to be effective in manipulating processes underlying language production, computational simulation studies indicate that the intracranial electric field distribution of tDCS is diffuse and the peak field strength amplitude is not located directly underneath the electrode (Rampersad et al., 2014). It was

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[1] Note that some studies also used the vertex, contralateral homologue, or extracephalic locations (e.g., contralateral cheek or shoulder) as reference positions (Vannorsdall et al., 2012; Westwood et al., 2017; Wirth et al., 2011). Although we here focus on the rSO as the reference region, additional simulations (not reported here) including the vertex or the contralateral homologue provided comparable results (i.e., highest field strengths outside of the targeted region).

estimated that the maximum field strength between two electrodes is obtained if the target electrode is approximately placed between 20 and 40 mm away from the target region (Rampersad et al., 2014). By this logic, placing the active electrode directly over the target site may induce a maximum field strength in regions adjacent to the targeted area. As a result, attributing changes in language production that are assumed to be caused by manipulating the regions of interest directly under the electrode can become more difficult. In spite of the well documented fact that electrode montage is an important aspect of tDCS experiments (Bikson, Datta, Rahman, & Scaturro, 2010; Wagner et al., 2007), the extent to which suboptimal electrode montages may at least partially account for the heterogeneity of results in language production studies has not been examined yet. The goal of the present study was to (1) provide an estimation of the electric field distributions of the two most commonly used electrode montages targeting the IFG and STG in language production tDCS studies, and (2) to present a number of alternative montages that may optimize the use of tDCS in language production studies.

Material and methods

Using the SimNIBS software (Opitz, Paulus, Will, Antunes, & Thielscher, 2015) we simulated the electric field distribution of anodal 1.5 mA tDCS with 5 × 7 cm electrodes (current density: 0.043 mA/cm²) in six different scenarios. We first tested whether the commonly used montage of placing the active electrode over the target region and the reference electrode over the contralateral supraorbital region provides the desired focality across the left IFG and STG, respectively. To address the second aim of our study, we used the computational findings reported by Rampersad et al. (2014) to adjust the position of the electrodes on the scalp as follows: (1) moving the centre of the active electrode approximately 3 cm anterior to the target region; (2) and placing the reference electrode in closer proximity to the active electrode; (3) turning the electrode so that the short edges of both electrodes approximately face each other. Electrode size was initially kept constant in order to directly compare the influence of electrode placement on the focality of tDCS. In another step, we reduced the

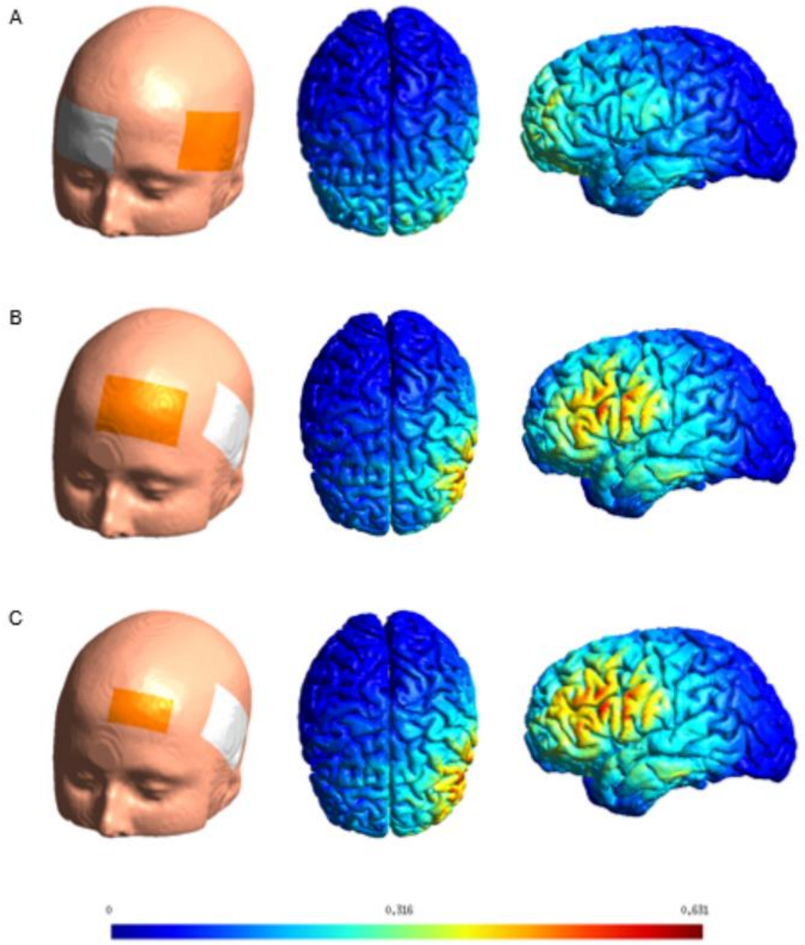

Figure 1. Electrode montages and electric field intensities for left inferior frontal gyrus tDCS. A: Conventional (electrodes 5 × 7 cm each). B: Alternative (electrodes 5 × 7 cm each). C: Improved (active electrode 3 × 5 cm, reference electrode 5 × 7 cm).

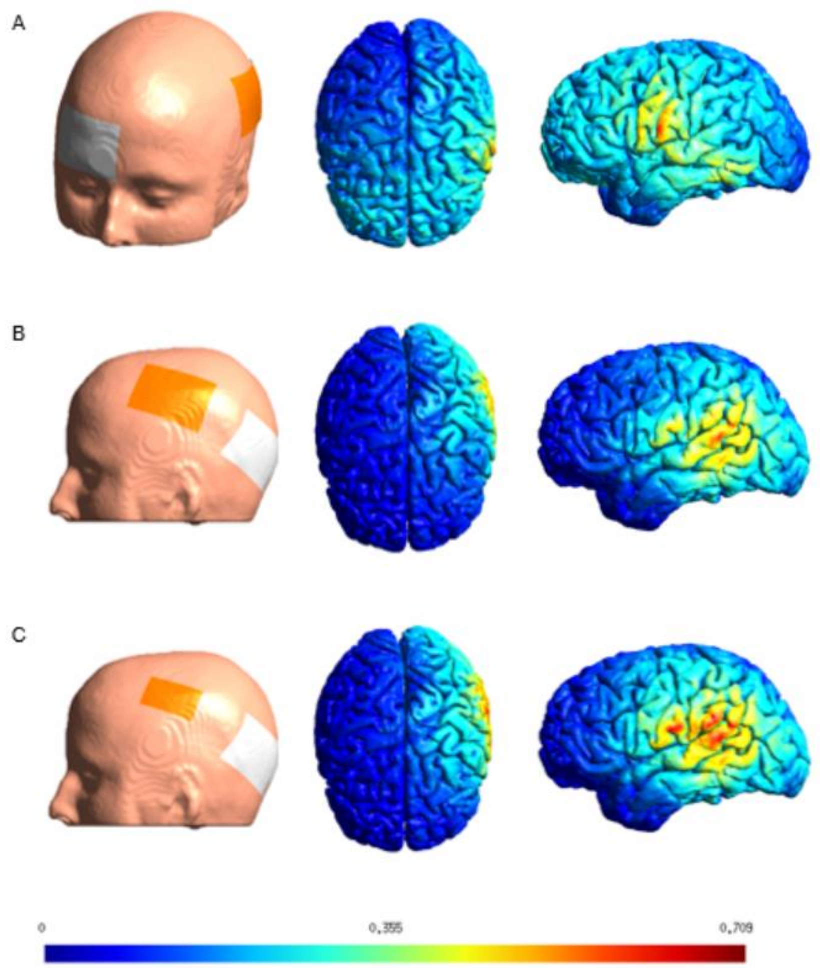

Figure 2. Electrode montages and electric field intensities for left posterior superior temporal gyrus tDCS. A: Conventional (electrodes 5 × 7 cm each). B: Alternative (electrodes 5 × 7 cm each). C: Improved (active electrode 3 × 5 cm, reference electrode 5 × 7 cm).

size of the active electrode (3 × 5 cm, current density: 0.1 mA/cm²) to investigate potential additional effects of changes in current density in the alternative montage. For all simulations, we chose an electrode-sponge setup, with a 1 mm thick electrode covered by a 2 mm thick sponge.

Results

IFG montage

Figure 1 displays the electrode montages and simulation results for the montages targeting the left IFG. The conventional montage (Figure 1A) does not seem optimal for this purpose. Field strength peaks (maximum: 0.451 V/m) were found in left middle and superior frontal regions, that is, anterior to the target region. Furthermore, the field distributions spread with decreasing intensity to left central and temporal as well as right frontal regions. The modified electrode montage (Figure 1B) showed a notable shift of the electric field. While the electric field did not reach the right hemisphere, the peak intensities (maximum: 0.560 V/m) were located around the IFG and central sulcus. Reducing the size of the active electrode (Figure 1C) further increased field strength (maximum: 0.631 V/m), while the field strength peaks remained centred around the left IFG and central sulcus.

STG montage

Figure 2 shows the results from simulations targeting the STG. The conventional montage (Figure 2A) resulted in field strength peaks (maximum: 0.596 V/m) centred on the medial part of the postcentral gyrus (i.e., anterior to the target region). Additionally, the induced electrical field covered significant parts of the left hemisphere and frontal parts of the right hemisphere, arguably due to the large distance between the electrodes. As for IFG stimulation, the alternative montage (Figure 2B) shifted the field intensity peaks towards the target region, with the highest field strength (maximum: 0.662 V/m) found in a rather large region including the STG and the inferior parietal lobule. Using a smaller active electrode (Figure 2C) further increased field strengths (maximum: 0.709 V/m) without affecting the distribution of the electric field. Note that both alternative montages again eliminated right hemispheric effects.

Discussion

Results from the simulations show that the electric field distribution of tDCS montages most commonly used in language production studies can be improved. Placement of the active electrode over the target region and the reference electrode over the contralateral supraorbital region results in highest field strengths anterior to the target region as well as additional frontal effects in the right hemisphere. These diffuse electrical field distributions may cause collateral activation of surrounding tissue and could in part explain the heterogeneous findings reported in previous studies. While there is no immediate reason to assume that the target regions were not exposed to the exogenous electric field at all, previously applied montages may not have been successful in reaching the desired spatial resolution of the electric field. Here, we provide a number of modified montages that may yield more focal peaks in electric field strength. Altering the montage by placing the electrodes anterior and posterior to the target region resulted in improved focality. Additionally, higher field intensities were found if the active electrode was smaller than the reference electrode (Bastani & Jaberzadeh, 2013; Nitsche et al., 2007). Using such a montage may thus target the desired region more directly and limit electric field exposure of surrounding regions. Subsequently, future studies reporting differences between real and sham tDCS conditions may find more reliable and unequivocal effects in language production tasks when targeting a region of interest. Notably, aside from the basic neuroscientific questions on language production, tDCS is currently being explored as a possible therapeutic intervention to treat aphasia (Elsner, Kugler, Pohl, & Mehrholz, 2015; Sandars, Cloutman, & Woollams, 2016; Sebastian, Tsapkini, & Tippett, 2016). Based on our findings, it is not unreasonable to assume that aphasic patients treated with tDCS may benefit from adopting simulation-based electrode montages to maximize focal electric field strengths.

It should be noted that the simulations were performed on a single brain which limits the generalisability of our results. Evidently, the efficacy of tDCS depends on many factors that include individual differences in gyral folding and physiological susceptibility to weak electric currents. However, for labs and clinics that do not have direct access to structural and functional neuroimaging facilities to individualize tDCS montages, simulations provide a pragmatic solution that outweighs the alternative of relying on "validated" montages. In sum, the current study may further stimulate the development of montages that will increase the robustness of findings and improve their interpretations.

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