Brain Stimulation 15 (2022) 32–34

Contents lists available at ScienceDirect

Brain Stimulation

journal homepage: http://www.journals.elsevier.com/brain-stimulation

Modulation of impulsive behaviours using transcranial random noise stimulation

A recent meta-analysis by Schroeder et al. (2020) [1] thoroughly summarised the accumulated knowledge on the potential of transcranial direct current stimulation (tDCS) in modulating inhibitory control. They concluded that the overall effect of tDCS appears to be small but significant and that targeting the right inferior frontal gyrus (rIFG) over the dorsolateral prefrontal cortex (DLPFC) might be more effective. Additionally, the stop-signal task (SST) as an outcome measure appeared to best capture the impact of tDCS on inhibitory control. Similarly, another recent meta-analysis by de Boer et al. (2021) [2] supported tDCS as a potential means to improve inhibitory performance, as measured by the go/no-go (GNG) task and SST.

Despite the above interesting findings, there is a scarcity of data on other transcranial electric stimulation (tES) methods in terms of their usability in modulating inhibitory control. Therefore, we describe here our experiment conducted to investigate the impact of transcranial random noise stimulation (tRNS), targeting the dorsolateral prefrontal cortex (DLPFC), on the modulation of inhibitory control. We recruited a mixed-gender sample of 60 healthy, right-handed volunteers aged 20–45 years (mean age 26.7 years). The study protocol was approved by the Ethics Committee of the North Savo Hospital District, Finland. Written informed consent was obtained from all the participants.

All the participants received one tRNS session and one sham stimulation session in a randomised, double-blinded, cross-over setting. TRNS was applied over the F3 and the F4 (corresponding to the left and right DLPFC), according to the international 10–20 system. Conductive rubber electrodes (5 × 5 cm), placed in two rectangle-shaped saline-soaked sponges, were used. The duration of the 2-mA high-frequency stimulation was 20 minutes, with a ramp-up period at the beginning and a ramp-down period at the end. Sham stimulation consisted of the ramping period only. Stimulation was performed with the DC-STIMULATOR PLUS (NeuroConn GmbH, Ilmenau, Germany). During the stimulation, participants sat calmly in a chair and followed a video with a windscreen view of a train journey. A cued GNG task [3] and SST [4] were used to measure selective attention and response inhibition before and after the tRNS/sham in both sessions.

Data were analysed with SPSS 27 statistical software (IBM SPSS Statistics for Windows, version 27.0. Armonk, NY: IBM Corp) and R version 4.1.1 (R Core Team (2021); R: A language and environment for statistical computing; R Foundation for Statistical Computing; Vienna, Austria). A mixed between–within subjects analysis of variance (ANOVA) was conducted to assess the impact of tRNS on the inhibitory failure rate in the GNG task and the stop-signal reaction time (SSRT) in the SST. Subjects who had significantly inhibited more or less than 50% of the time were excluded prior to the analysis, as the subtraction method was used to calculate SSRTs [4]. Power calculations were performed to compute the numbers of individuals required to detect the effect of tRNS on performance in either the GNG task or SSRT as significant. We used a simulation-based method with the "simr" R package, in which the number of participants was artificially extended to a large enough number to give an adequate degree of power for a linear mixed model analysis corresponding to the utilized ANOVA.

No main effect of stimulation was observed on inhibitory failure rates in the GNG task (Wilks' Lambda = 1.0, $F(1, 58) = 0.015$, $p = .904$, $\eta_p^2 = 0.000$), and the interaction of stimulation x time was non-significant (Wilks' Lambda = 0.967, $F(1, 58) = 1.992$, $p = .163$, $\eta_p^2 = 0.033$). There was, however, a significant effect for time before vs. after the intervention (Wilks' Lambda = 0.894, $F(1, 58) = 6.908$, $p = .011$, $\eta_p^2 = 0.106$). Similarly, SSRTs showed neither a significant main effect for stimulation (Wilks' Lambda = 0.977, $F(1, 42) = 0.969$, $p = .331$, $\eta_p^2 = 0.023$) nor a significant interaction of stimulation x time (Wilks' Lambda = 0.999, $F(1, 42) = 0.046$, $p = .831$, $\eta_p^2 = 0.001$). A significant main effect was again observed for time before vs. after the intervention (Wilks' Lambda = 0.797, $F(1, 42) = 10.710$, $p = .002$, $\eta_p^2 = 0.203$). The SSRT achieved a projected power of 80% at approximately 10,000 participants, whereas the GNG task achieved a power of 80% at approximately 150 participants. (see Fig. 1)

We observed no effect of tRNS on SSRT or inhibitory failure rates in the GNG task. Nevertheless, time predicted an improvement in performance in both tasks, suggesting a learning effect. In their meta-analysis, Schroeder et al. (2020) suggested that the overall effect of tDCS was small but significant. Targeting the right inferior frontal gyrus (rIFG) appeared to surpass the DLPFC in effect, which may partially explain our findings. Nevertheless, Schroeder et al. (2020) observed that the stimulation effect diminished significantly after trim-and-fill analysis of bias and was not statistically significant after PET–PEESE analysis. Furthermore, to the best of our knowledge, the impact of tRNS on inhibitory control has only been investigated in three previous studies [5–7]. In line with our findings, no effect was observed for online or offline tRNS in a GNG task when stimulating rIFG [5]. However, another study found a decrease in go-trial reaction times after repeated sessions

https://doi.org/10.1016/j.brs.2021.11.002

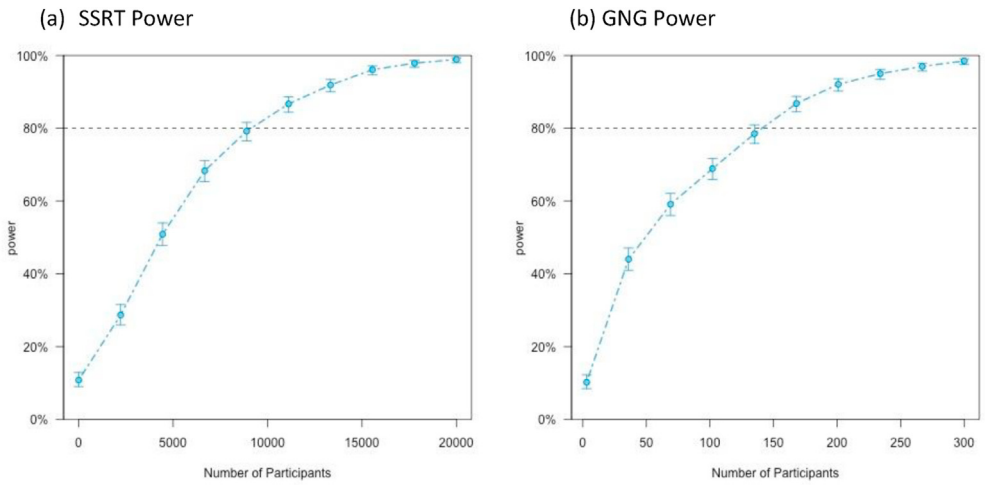

Fig. 1. Projected power of (a) SSRT and (b) GNG experiments as a function of the extended number of simulated participants.

of tRNS on the DLPFC [6]. Furthermore, 10 minutes of tRNS over the dominant primary motor cortex led to slowed reaction times and enhanced task accuracy in the GNG task during and after stimulation [7].

A large degree of heterogeneity is characteristic of tES studies. The current types, stimulation times and electrode placements vary, and tES has been applied both online and offline, and in single and multiple session settings. Therefore, direct comparisons of the conducted studies are very challenging [8], and it remains unclear which factors contribute most when investigating the potential effects of tES on inhibitory control. These issues remain topics for future study. Furthermore, our power calculations indicate that a future experiment to detect an observable effect of tRNS could be credibly achieved for the GNG task, but not for the SST. In the light of our power calculations, many of the previously conducted studies appear modest in size. To improve the quality of future studies, we would recommend a standard practice of publishing sample size calculations based on each new study to provide more specific guidance for future research.

Declaration of competing interest

None. MV has received a grant from the Finnish Medical Foundation.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.brs.2021.11.002.

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17 October 2021
Available online 3 November 2021