

Real-Time Modulation of Cerebral Blood Flow by tDCS During a Cognitive Task

Casandra I. Montoro Aguilar, Pilar Ruiz-Medina, Stefan Duschek, Gustavo A. Reyes del Paso

University of Jaén (Spain)

UMIT-University for Health Sciences Medical Informatics and Technology (Austria)

INTRODUCTION & AIM

Functional transcranial Doppler ultrasonography (fTCD) is a technique used to record cerebral blood flow (CBF). Its high temporal resolution makes it a highly useful method for studying CBF responses during cognitive performance, for example during arithmetic tasks (Connaughton et al., 2017; Montoro et al., 2015; Moreel et al., 2026). Transcranial direct current stimulation (tDCS) has been applied for the modulation of different cognitive aspects (Hartmann et al., 2024; Hussain et al., 2024; Lazzaro et al., 2022; Mosbacher et al., 2020), with inconsistent results. tDCS has sometimes shown observable changes in cognitive task performance (Hartmann et al., 2024), whereas on other occasions the underlying effects were not reflected on a behavioral level (Mosbacher et al., 2020). Moreover, the effects of tDCS on performance during arithmetic tasks while fTCD is used to record changes in CBF remain unexplored. These findings could offer new insights into the mechanisms underlying the cognitive effects of neuromodulation.

METHOD

- **Participants:** 47 healthy right-handed young adults, undergraduate psychology students.
- **Conditions:** Anodal tDCS over P3 (cathode over Fp2) or placebo (sham) for 20 minutes at 1.5 mA (n = 21 verum + 26 sham).
- **Design:** Between-groups.
- **Task:** Simple addition arithmetic task (Montoro et al., 2015).
 - ✓ Presentation of a fixation point, a black cross on a white background, whose disappearance signals the appearance, after a 5-second delay, of two digits to be added. The task consists of 15 trials.
 - ✓ Instructions: Indicate the last digit of the sum as quickly and accurately as possible.
 - ✓ Performance: Correct responses, errors, and reaction time.
- **Physiological measures:** Recording of CBF velocity using fTCD with the Multi-Dop L2 system (DWL Elektronische Systeme, Sipplingen, Germany).
 - ✓ The middle cerebral artery (MCA) was recorded bilaterally at a depth of 48–55 mm.
- **Procedure:** tDCS was applied for 20 minutes; subsequently, an fTCD recording was performed simultaneously with the execution of the arithmetic task (See Figure 1. Procedure).

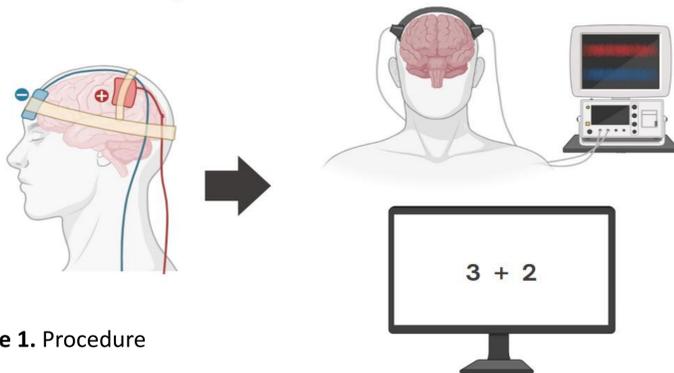


Figure 1. Procedure

ANALYSES:

- **Five components were visually identified:** **A)** An early component associated with the disappearance of the fixation point; **B)** Three late components associated with the appearance of the numbers and task execution (B1, B2, and B3); **C)** A decrease associated with recovery processes and return to baseline.
- **Mixed repeated-measures ANOVA:** Components as a within-subject factor, tDCS condition as a between-subject factor.
- **Post-hoc analyses:** Pairwise comparisons of estimated marginal means with Bonferroni correction.
- **Independent-samples t-test** for task performance measures.
- **Bivariate correlations** between task performance and components.

REFERENCES

- Connaughton, V. M., Amiruddin, A., Clunies-Ross, K. L., French, N., & Fox, A. M. (2017). Assessing hemispheric specialization for processing arithmetic skills in adults: A functional transcranial doppler ultrasonography (fTCD) study. *Journal of Neuroscience Methods*, 283, 33-41. <https://doi.org/10.1016/j.jneumeth.2017.03.010>
- Hartmann, M., & Dumureau, M. (2025). Anodal High-definition Transcranial Direct Current Stimulation Over the Left (but not Right) Parietal Cortex Facilitates Mental Arithmetic. *Journal of Cognitive Enhancement*, 9(1), 51-66. <https://doi.org/10.1007/s41465-024-00314-0>
- Hussain, M., Davis, N. J., & Benn, Y. (2024). A single tDCS session can enhance numerical competence. *Neuropsychologia*, 193, 108760. <https://doi.org/10.1016/j.neuropsychologia.2023.108760>
- Lazzaro, G., Fucà, E., Caciolo, C., Battisti, A., Costanzo, F., Varuzza, C., Vicari, S., & Menghini, D. (2022). Understanding the Effects of Transcranial Electrical Stimulation in Numerical Cognition: A Systematic Review for Clinical Translation. *Journal of Clinical Medicine*, 11(8), 2082. <https://doi.org/10.3390/jcm11082082>
- Montoro, C. I., Duschek, S., Muñoz Ladrón De Guevara, C., Fernández-Serrano, M. J., & Reyes Del Paso, G. A. (2015). Aberrant cerebral blood flow responses during cognition: Implications for the understanding of cognitive deficits in fibromyalgia. *Neuropsychology*, 29(2), 173-182. <https://doi.org/10.1037/neu0000138>
- Moreel, L., Gerrits, R., & Fias, W. (2026). Hemispheric specialization in mental arithmetic: Insights from functional transcranial Doppler Sonography. *Brain and Cognition*, 193, 106391. <https://doi.org/10.1016/j.bandc.2025.106391>
- Mosbacher, J. A., Brunner, C., Nitsche, M. A., & Grabner, R. H. (2020). Effects of Anodal tDCS on Arithmetic Performance and Electrophysiological Activity. *Frontiers in Human Neuroscience*, 14, 17. <https://doi.org/10.3389/fnhum.2020.00017>

RESULTS & DISCUSSION

No significant differences were observed in task performance measures (accuracy and reaction time). Regarding the CBF response in the left MCA, no significant component \times condition interaction was observed ($F(5,225) = 7.272, p = .287$); however, in the right MCA a significant component \times condition interaction was found ($F(5,225) = 3.676, p = .017$) for components A ($-.18 \pm 1.03$ vs. $-.56 \pm 1.13, p = .022$), B3 (2.66 ± 2.74 vs. $.89 \pm 3.15, p = .046$), and component C (2.34 ± 2.87 vs. $-.16 \pm 2.74, p = .004$). The effect was marginal for component B2 (2.80 ± 2.83 vs. $1.03 \pm 3.33, p = .055$) (See Figure 2. Changes in CBF velocity). Marginal correlations were observed between component C in the right MCA and correct responses ($r = .292, p = .057$) and errors ($r = -.292, p = .057$).

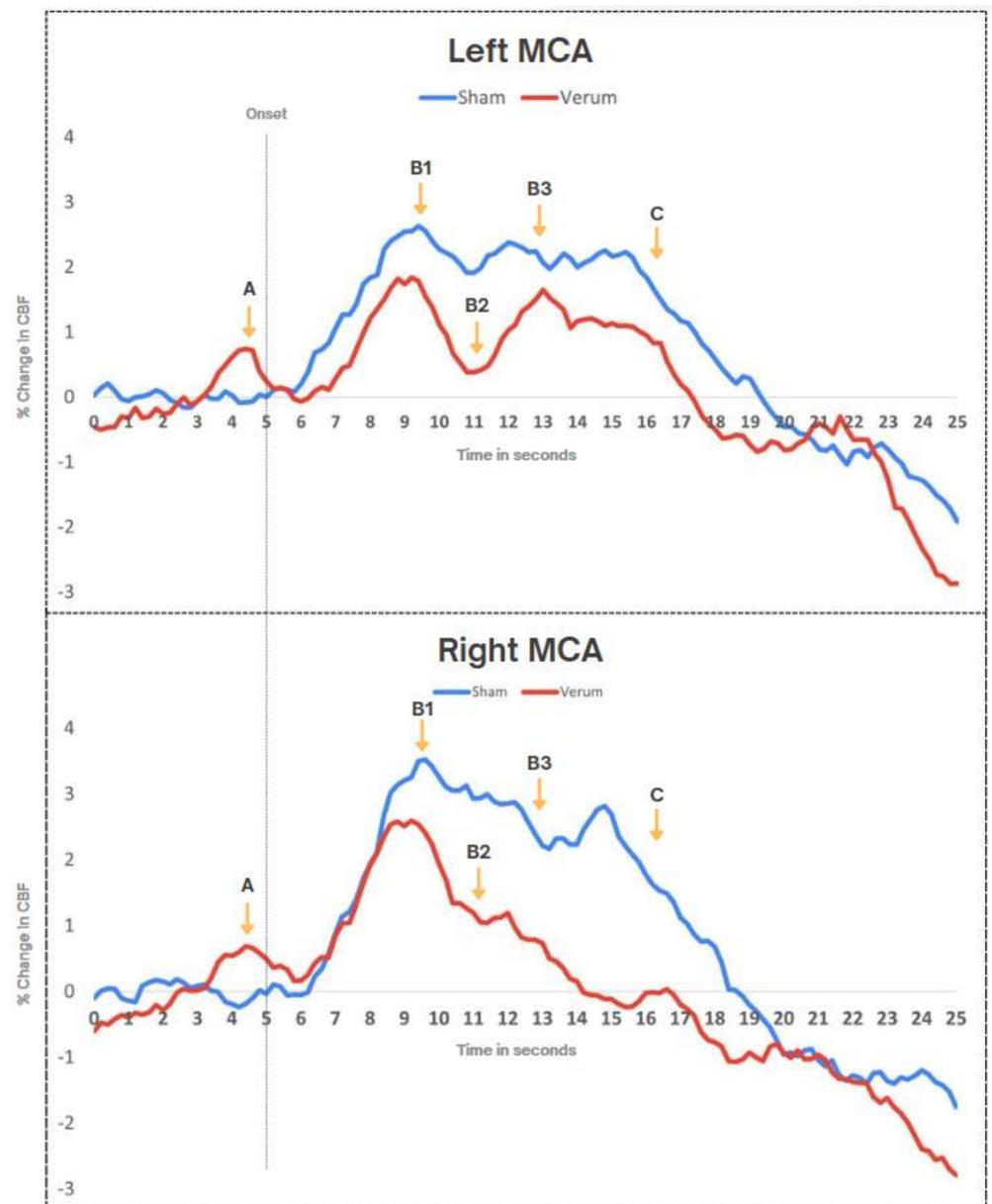


Figure 2. Changes in CBF velocity

The results show an effect of anodal tDCS over P3 on CBF during the arithmetic task execution, with modulations in CBF observed only in the right MCA, increasing the percentage change in CBF velocity prior to the appearance of the task and decreasing during and after the execution of the task. However, tDCS did not produce behavioral effects on task performance. These findings suggest that tDCS may be facilitating preparatory activation while reducing the activity of areas irrelevant to the task. These results highlight the potential of tDCS in modulating CBF responses and demonstrate that fTCD is an effective technique for evaluating CBF changes induced by tDCS.

CONCLUSION

Anodal tDCS applied over the P3 area modulates CBF associated with an arithmetic-type cognitive task, although this effect is not observable at the behavioral level during task performance, maybe due to a ceiling effect of the task used.

Funding: Research supported by a grant from the Consejería de Universidad, Investigación e Innovación en materia de I+D+i de la Junta de Andalucía (ProyExcel_00374) and a competitive grant for a predoctoral position within the Convocatoria de Ayudas para Contratos Predoctorales para la Formación de Doctores (PRE2023-UJA-01).