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No tDCS augmented working memory training benefit in undergraduates rewarded with course credit

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A B S T R A C T

Background: The goal of working memory (WM) training is to expand capacity of this executive function. Transcranial direct current stimulation (tDCS) paired with WM training is more consistent than either alone. We have reported that tDCS targeting frontal and/or parietal regions enhanced theta phase locking, reduced alpha power, and strengthened theta-gamma phase amplitude coupling.

Objective: To determine whether tDCS to frontal or parietal sites optimized WM training gains we preregistered a tDCS-WM training study.

Methods: 80 undergraduates were randomly assigned to one of four anodal tDCS montages: frontal (F4), parietal (P4), alternating (P4–F4), and sham (P4 or F4). Participants completed 5-training sessions over one week and returned for follow-up testing after 30 days of no-contact.

Results: No group showed significant improvement in trained or transfer task performance at the end of training nor at follow-up.

Conclusions: This null finding marks a failure to replicate in undergraduates training benefits observed in graduate students. We argue that motivation is essential to elicit improved performance in training protocols.

Introduction

Working memory (WM) allows us to maintain and manipulate a small amount of information over a brief time period. WM is important for upper level cognition but improvement via training produces modest outcomes (reviewed in Ref. [1–3]). Recent protocols pairing training with transcranial direct current stimulation (tDCS) benefit WM and other abilities more than training alone [4]. Previously we reported that WM training paired with anodal tDCS (alternating between F4, P4) and pre-/post- EEG selectively improved performance in the active tDCS group [5]. Behavioral improvement was accompanied by neural differences including lower alpha power and enhanced anterior-posterior theta phase locking [5], and theta-gamma phase-amplitude coupling [6]. Other research shows lower alpha power correlates with enhanced attention [7] and theta phase coupling leading to better WM performance [8]. We preregistered a replication and extension study[1] to include follow-up testing and separate F4 and P4 montages to determine what drove the previous tDCS-linked WM benefit. However, the change of population (undergraduates not graduate students) produced no training related WM improvement (see Fig. 1).

Methods

Eighty neurotypical undergraduates consented to participate (M = 22.6, SD = 5.8, 49 female). The IRB approved all protocols. At follow-up, 41 participants completed the WM task, 75 participants completed most or all of the transfer tasks (19 P4–F4, 19 F4, 18 P4, 20 sham).

Each session, participants completed a 5-item change detection WM task presenting common objects or novel items (see Supplementary Methods). Sessions 1–6 were sequential, Session 7 occurred ~1 month later. HD-EEG was recorded during Sessions 1 and 7. Participants completed independent WM measures (Session 2: OSPAN [9], forward/backward digit span). Sessions 2–5 included online active or sham tDCS. Session 7 included the WM task, and transfer tasks (spatial 2-back, math, Go/No-Go, WAIS symbol).

Participants were randomly assigned to different montages of anodal tDCS: PFC (F4), PPC (P4), sham (either F4 or P4) or alternating PFC/PPC (P4–F4); cathode was placed on the left cheek. Current (1.5 mA, 15 minutes) was delivered via two electrodes (5×7 cm^2) (Eldith MagStim, GmbH, Ilmenau, Germany). Sham began and ended with a 20 s ramp up/down. Participants completed a post-tDCS questionnaire and reported no adverse effects. One participant (P4–F4) was incorrectly administered ABBB order instead of ABAB and two participants received 2 mA for 20 minutes on Session 4.

[1] osf.io/68aux. Note: the preregistered report incorrectly referenced a tDCS intensity of 2mA instead of the 1.5mA we used to be consistent with our prior study [7].

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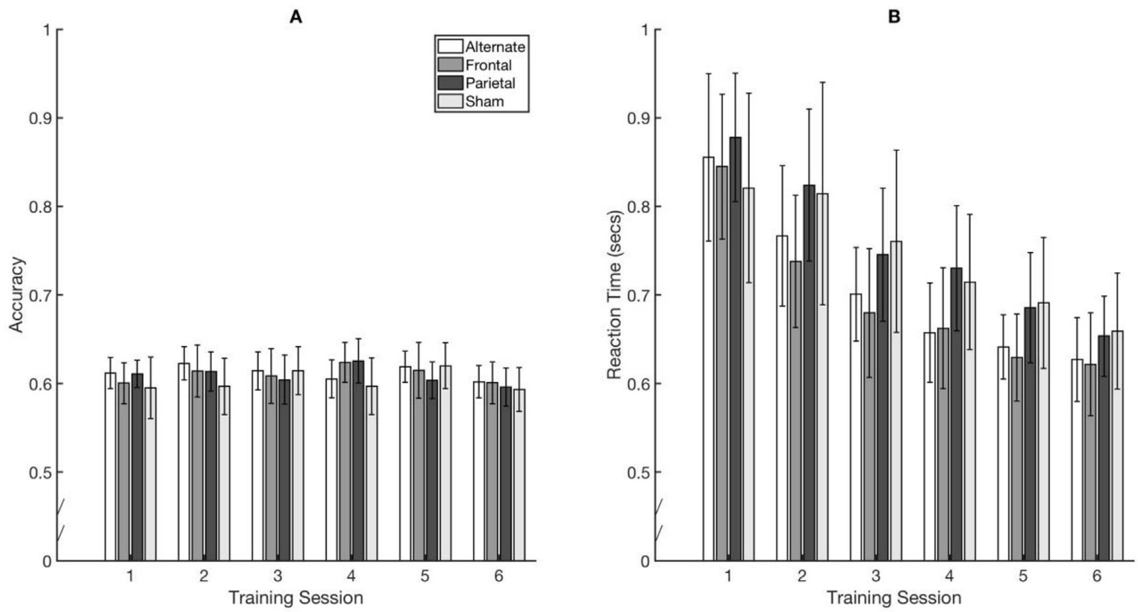

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Fig. 1. Behavioral performance by session and group (alternating PFC/PPC, PFC, PPC, sham) for: **A)** proportion correct, and **B)** median correct reaction time.

Results

Baseline measurements (OSPAN, forward/backward digit span) assured equivalent group performance (ps > 0.37). To assess training related WM improvement, a mixed ANOVA with the within-subjects factor of session and the between-subjects factor of group (sham, F4, P4, P4/F4) revealed no significant effects on accuracy (session: $F(5, 380) = 1.95$, $p = 0.09$, $\eta^2 = 0.025$, group: $F(3, 76) = 0.24$, $p = 0.87$; interaction, $F(15, 380) = 0.94$, $p = 0.52$). However, reaction times significantly improved ($F(3.1, 232.1) = 84.6$, $p < 0.001$, $\eta^2 = 0.53$). Sessions 1–4 were slower than Sessions 5–7. There remained no main effect of group ($F(3,76) = 0.72$ $p = 0.54$) and no interaction ($F(9.2, 232.1) = 1.22$, $p = 0.28$). We conducted two post hoc analyses selecting those who showed numeric improvement in accuracy, or reaction time. Neither analysis revealed a significant group difference across sessions 1–6 (group ps > .2; interaction ps > .08) or at follow up (group ps > .3; interaction ps > .06).

At follow-up (Session 7), there were no significant group differences on the transfer tasks (Go/NoGo: $F(3, 71) = 2.43$, $p = 0.07$ – driven by the $p = 0.059$ pairwise difference between the PFC and alternating groups; functional math: $F(3, 71) = 2.07$, $p = 0.11$; spatial 2-back: non-target score: $F(3, 71) = 0.11$, $p = 0.95$, target score: $F(3, 71) = 1.13$, $p = 0.34$; processing speed: $F(3, 71) = 0.8$, $p = 0.5$).

Discussion

Undergraduates completed 5-sessions of paired WM training and anodal tDCS targeting right frontal, parietal or both areas. Everyone showed faster response times with practice, but there were no additional benefits of tDCS. Follow-up testing revealed no delayed benefits or evidence of transfer. These data failed to replicate our prior findings showing a significant benefit of tDCS-enhanced WM training [5]. We offer the data as a cautionary tale. We speculate that changing our participant population from intrinsically motivated graduate students to undergraduates there to earn course credit, regardless of performance, elicited less engagement. It is known that motivation predicts tDCS benefits [10]. Thus, a limitation of this project is that we cannot discriminate between the possibilities that there was no effect of tDCS, or that unmotivated people do not benefit from training. Researchers working to expand tDCS applications should assure participant engagement via appropriate incentive. Furthermore, we preregistered the study and deliberately did not 'peek' at the data to see that a course correction was merited. Training studies are challenging to conduct but have important implications for public health. Identifying additional pitfalls will hopefully benefit future research.

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Declaration of competing interest

The authors have no conflicts of interest to disclose.

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This work was preregistered as Open Science Framework: Berryhill, M. (2018, February 26). Working Memory Training Benefits from tDCS. Retrieved from: osf.io/68aux.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.brs.2020.08.015.

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