A novel electric field modeling meta-analysis method to identify prefrontal tDCS-related working memory improvement

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Introduction

Over the past decades research studies have explored whether transcranial direct current stimulation (tDCS) can improve cognitive abilities, including working memory (WM). Meta-analyses suggested that tDCS effects on WM are small, due to large variability **[1,2]**. Inter-experimental differences in electrode position, size, orientation and material, as well as differences in applied intensity constitute a considerable part of tDCS-related variability. To control for inter-experimental variability, we propose a new meta-analytic approach, combining effect size estimates with electric field simulation.

Methods

Based on a literature search 68 articles with 87 total experiments were identified suitable for our meta-analysis. Studies were included if they provided sham and/or baseline controlled, single session, anodal, prefrontal tDCS on WM performance. Of the selected experiments, n = 69 experiments targeted left prefrontal cortex, and n = 18 targeted right prefrontal cortex.

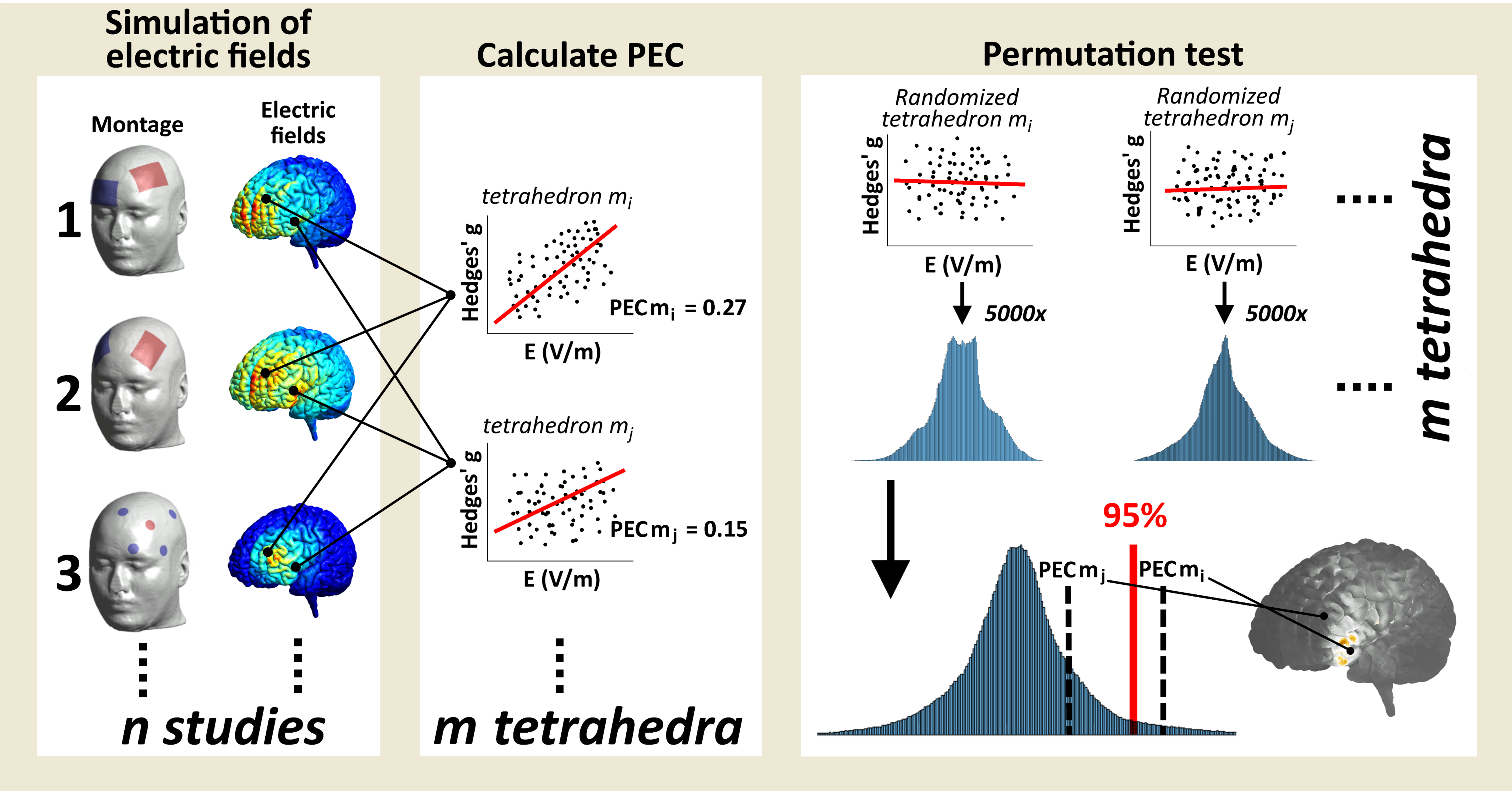

Fig. 1 Analysis pipeline for relating electric field distributions to WM performance

Our analysis pipeline involves four steps:

I) Calculating effect sizes of sham-controlled working memory outcome parameters (Hedges' g).

II) Simulation of electric field distributions for each montage and intensity with SimNIBS version 3.2. **[3]**. A typical young male head model was used (Fig. 1, left panel).

III) Compute performance – electric field correlation (PEC) between effect size and norm of the electric field for each tetrahedron (individual volumetric element in gray matter, m = ~9.8 x 10^5; Fig. 1, middle panel).

IV) To test for significance, a permutation test was performed in which PEC values are compared to a null-hypothesis model (5000 randomized correlations of shuffled Hedges' g value and electric field strength). PEC values were compared to the null-hypothesis model distribution yielding a (one-sided) probability (p) value, where the 95^{th} percentile of the distribution corresponds to p = 0.05 (Fig.1, right panel).

Results

We found a significant volume at the border of the lower left dorsolateral prefrontal cortex and left inferior frontal cortex, between Brodmann area 45 and 47 (Fig. 2) . Maximum PEC was 0.279 (p = 0.010) at MNI coordinates [-51, 39, 4]. This PEC value corresponds to 7.8 % explained variance, which amounts to a medium-sized effect. A total volume of 1.16 cm3 had a PEC value that reached significance (PEC > 0.199, p < 0.05). A similar region in the opposite hemisphere was identified for right prefrontal tDCS studies.

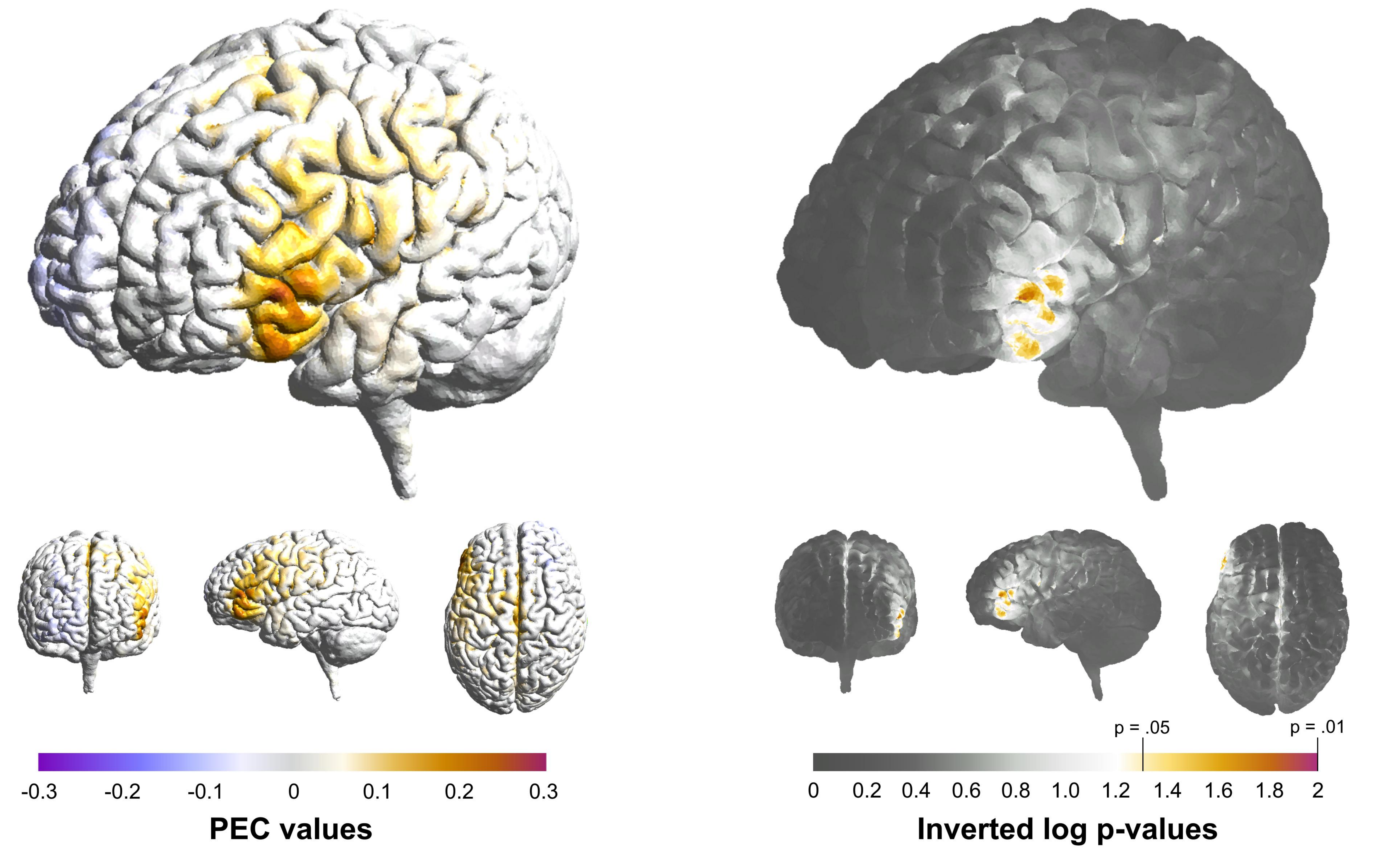

Fig. 2 Left: PEC values representing the relationship between electric field strength and behavioral effect size. Right: Inverted Log10 p-values associated with the PEC values. Inverted Log-p of 1.31 and 2 correspond to p = 0.05 and p = 0.01, respectively.

Discussion

Although previous analyses have shown only small effects of tDCS on WM, these results indicate that substantially larger effect sizes can be achieved when controlling for montage variability. Therefore, our method introduces a new way of analyzing across different studies. Furthermore, our results provide practical insights for future tDCS studies that aim to affect WM function.

References

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