

CORRECTION

Correction: Transcranial direct current stimulation in attention-deficit hyperactivity disorder: A meta-analysis of neuropsychological deficits

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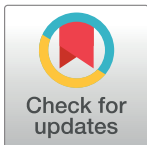
The values of three out of the ten studies (bolded in the Tables) included in this meta-analysis were entered incorrectly due to copy-pasting errors. As a result, there are errors in Tables 1–4, Fig 2, and the Abstract, Results, and Discussion sections. The authors confirm that these modifications do not alter the conclusions of the study.

In Table 1, there are errors in results under the column titled “Hedges’ g” for the studies “Cosmo et al (2015)”, “Nejati et al (2017) experiment 1”, “Nejati et al (2017) experiment 2”, and “Sotnikova et al (2017)”.

In Table 2, there are errors in results under the column titled “Hedges’ g” for the studies “Nejati et al (2017) experiment 1” and “Nejati et al (2017) experiment 2”.

In Tables 3 and 4, there are errors in the results reported in the “Analysis” rows under the column subheadings of “E”, “Z”, “p-value”, “Fail-safe number”, “KS test”, “Qtotal”, and “p-value”.

Please see the correct Tables 1–4 here.



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Table 1. Characteristic of studies included in meta-analysis for the effects of tDCS on inhibitory control.

| # | Authors | N | Mean age | tDCS montage (target/reference) | Intensity | Duration | Polarity | On-/off-line | Control | Task | Outcome | Hedges' g | | | | |
|---|----------------------------------|----|---------------------|---|-------------------------|-----------------|----------|--------------------------------------|------------------------|-------------------------|---------------------------|-----------|------|--------------|------------------|-------|
| 1 | Allenby et al (2018) | 37 | 37.17 (range 18–56) | F3/Fp2 (25 cm ² both) | 2 mA | 3 days x 20 min | Anodal | Offline | Baseline + sham | CPT | False positive errors | 0.42 | | | | |
| | | | | | | | | | | | True positive errors | -0.06 | | | | |
| | | | | | | | | | | | Response time | -0.11 | | | | |
| | | | | F3/Fp2 (25 cm ² both) | 2 mA | 3 days x 20 min | Anodal | Offline | Baseline + sham | SST | Reaction time | -0.18 | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| 2 | Bandeira et al (2016) | 9 | 11.1 ± 2.8 | F3/Fp2 (35 cm ² both) | 2 mA | 5 days x 30 min | Anodal | Offline | Baseline | NEPSY II | Total errors | 0.12 | | | | |
| | | | | | | | | | | | Completion time | 0.54 | | | | |
| 3 | Breitling et al (2016) | 21 | 14.33 (range 13–17) | F8/mastoid (35 cm ² both) | 1 mA | 20 min | Anodal | Online | Sham | Flanker task | Omission errors | -0.11 | | | | |
| | | | | | | | | | | | Comission errors | 0.46 | | | | |
| | | | | | | | | | | | Reaction time | -0.14 | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | F8/mastoid (35 cm ² both) | 1 mA | 20 min | Cathodal | Online | Sham | Flanker task | Omission errors | -0.60 |
| | | | | | | | | | | | | | | | Comission errors | 0.17 |
| | | | | | | | | | | | Reaction time | 0.13 | | | | |
| | | | | | | | | | | | Reaction time variability | -0.02 | | | | |
| 4 | Cosmo et al (2015) | 30 | 31.8 ± 11.6 | F3/F4 (35 cm ² both) | 1 mA | 20 min | Anodal | Offline | Sham | Go/No-go task (letters) | Correct responses | 0.06 | | | | |
| | | | | | | | | | | | Omission errors | -0.08 | | | | |
| | | | | | | | | | | | Comission errors | 0.26 | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | Go/No-go task (fruits) | Correct responses | -0.12 | | | | | |
| | | | | | | | | | | | Omission errors | -0.05 | | | | |
| | | | | | | | | | | | Comission errors | -0.15 | | | | |
| 5 | Munz et al (2015) | 14 | 12.3 ± 1.4 | F3+F4/both mastoids (0.5 cm ² all) | 0–0.25 mA (oscillatory) | 5 x 5 min | Anodal | Offline | Sham | Go/No-go task | Reaction time | 0.88 | | | | |
| | | | | | | | | | | | Reaction time variability | 0.83 | | | | |
| 6 | Nejati et al (2017) experiment 1 | 15 | 10 ± 2.2 | F3/F4 (25 cm ² both) | 1 mA | 15 min | Anodal | Offline | Sham | Go/No-go task | Go accuracy | 0.13 | | | | |
| | | | | | | | | | | | No-go accuracy | 0.08 | | | | |
| | | | | | | | | | | | Reaction time | 0.24 | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | Stroop task | Accuracy | 0.70 | | | | |
| | | | | | | | | | | | Reaction time | 1.09 | | | | |
| 7 | Nejati et al (2017) experiment 2 | 10 | 9 ± 1.8 | F3/Fp2 (25 cm ² both) | 1 mA | 15 min | Anodal | Offline | Sham | Go/No-go task | Go accuracy | 0.41 | | | | |
| | | | | | | | | | | | No-go accuracy | 0.66 | | | | |
| | | | | | | | | | | | Reaction time | -0.24 | | | | |

(Continued)

Table 1. (Continued)

| # | Authors | N | Mean age | tDCS montage (target/reference) | Intensity | Duration | Polarity | On-/off-line | Control | Task | Outcome | Hedges' g |
|---|---------------------------|----|-------------|---|-----------|----------|----------|--------------|---------|---------------|---|-----------|
| | | | | F3/Fp2 (25 cm ² both) | 1 mA | 15 min | Cathodal | Offline | Sham | Go/No-go task | Go Accuracy | 0.41 |
| | | | | | | | | | | | No-go accuracy | 1.21 |
| | | | | | | | | | | | Reaction time | -0.68 |
| 8 | Soltaninejad et al (2015) | 20 | Range 15–17 | F3/Fp2 (35 cm ² both) | 1.5 mA | 8 min | Anodal | Offline | Sham | Go/No-go task | Go accuracy | -0.05 |
| | | | | | | | | | | | No-go accuracy | 0.03 |
| | | | | | | | | | | | Reaction time | 0.23 |
| | | | | | | | | | | Stroop task | Accuracy | 0.57 |
| | | | | | | | | | | | Reaction time | 0.23 |
| | | | | F3/Fp2 (35 cm ² both) | 1.5 mA | 8 min | Cathodal | Offline | Sham | Go/No-go task | Go accuracy | -0.54 |
| | | | | | | | | | | | No-go accuracy | 0.73 |
| | | | | | | | | | | | Reaction time | -0.02 |
| | | | | | | | | | | Stroop task | Accuracy | 0.33 |
| | | | | | | | | | | | Reaction time | 0.11 |
| | | | | | | | | | | | Reaction time | 0.02 |
| 9 | Sotnikova et al (2017) | 13 | 14.33 ± 1.3 | F3 (13 cm ²)/Cz (35 cm ²) | 1 mA | 30 min | Anodal | Online | Sham | Go/No-go | accuracy (hits +correct rejections/total number of stimuli) | -0.68 |
| | | | | | | | | | | | Reaction time | 0.24 |
| | | | | | | | | | | | Reaction time variability | -0.05 |

tDCS = transcranial direct current stimulation; F3 = left dlPFC; F4 = right dlPFC; F8 = inferior frontal gyrus; Fp1 = left supraorbital area; Fp2 = right supraorbital area; online = task performance during tDCS; offline = task performance after tDCS; CPT = [Conners Continuous Performance Task](#); SST = Stop Signal Task (SST).

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Table 2. Characteristic of studies included in the meta-analysis for the effects of tDCS on working memory.

| # | Authors | N | Mean age | tDCS montage (target/reference) | Intensity | Duration | Polarity | On-/off-line | Control | Task | Outcome | Hedges' g | | |
|---|----------------------------------|----|---------------------------|--|-------------------------|-----------------|----------|--------------|-----------------|---------------------|-------------------------------------|---------------------------|---------------|-------|
| 1 | Bandeira et al (2016) | 9 | 11.1 ± 2.8 | F3/Fp2 (35 cm ² both) | 2 mA | 5 days x 30 min | Anodal | Offline | Baseline | Digit span forward | Amount | -0.87 | | |
| | | | | | | | | | | Digit span backward | Amount | -0.40 | | |
| | | | | | | | | | | Corsi cube forward | Amount | -0.45 | | |
| | | | | | | | | | | Corsi cube backward | Amount | 0.08 | | |
| 2 | Nejati et al (2017) experiment 1 | 15 | 10 ± 2.2 | F3/F4 (25 cm ² both) | 1 mA | 15 min | Anodal | Offline | Sham | 1-back task | Accuracy | 0.08 | | |
| | | | | | | | | | | | Reaction time | 1.39 | | |
| 3 | Nejati et al (2017) experiment 2 | 10 | 9 ± 1.8 | F3/Fp2 (25 cm ² both) | 1 mA | 15 min | Anodal | Offline | Sham | 1-back task | Accuracy | 1.15 | | |
| | | | | | | | | | | | | Reaction time | 0.96 | |
| | | | | F3/Fp2 (25 cm ² both) | 1 mA | 15 min | Cathodal | Offline | Sham | 1-back task | Accuracy | 0.54 | | |
| | | | | | | | | | | | | Reaction time | 0.54 | |
| 4 | Prehn-Kristensen et al (2014) | 12 | 12.1 (range 10–14) | F3+F4/both mastoids (0.5 cm ² all) | 0–0.25 mA (oscillatory) | 5 x 5 min | Anodal | Offline | Baseline + sham | Digit span | Amount | -0.61 | | |
| 5 | Soff et al (2017) | 15 | 14.2 ± 1.2 | F3 (3.14 cm ²)/ Cz (12.5 cm ²) | 1 mA | 5 days x 20 min | Anodal | Offline | Baseline + sham | QB (1-back) task | QB score (errors and reaction time) | 0.50 | | |
| 6 | Sotnikova et al (2017) | 13 | 14.33 ± 1.3 | F3 (13 cm ²)/ Cz (35 cm ²) | 1 mA | 30 min | Anodal | Online | Sham | 1-back task | Accuracy | -0.99 | | |
| | | | | | | | | | | | | Reaction time | -0.05 | |
| | | | | | | | | | | | | Reaction time variability | 0.18 | |
| | | | | | | | | | | | | 2-back task | Accuracy | -1.14 |
| | | | | | | | | | | | | | Reaction time | 0.65 |
| | | | Reaction time variability | 1.06 | | | | | | | | | | |

tDCS = transcranial direct current stimulation; F3 = left dlPFC; F4 = right dlPFC; Fp2 = right supraorbital area; online = task performance during tDCS; offline = task performance after tDCS; QbTest = Quantified Behavior Test.

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Table 3. Meta-analysis results for the effects of tDCS on inhibitory control in ADHD patients.

| Cumulative effect size | | | | | | | Normality | | Heterogeneity | |
|------------------------|----|--------------|--------------------|--------------|---------------|------------------|--------------|--------------|---------------|---------|
| Analysis | N | \bar{E} | 95% CI | Z | p-value | Fail-safe number | KS test | p-value | Qtotal | p-value |
| Polarity-independent | | | | | | | | | | |
| All studies | 46 | 0.117 | 0.008–0.252 | 2.104 | 0.0353 | 79 | 0.105 | LB 0.200 | 46.13 | 0.425 |
| dIPFC only | 38 | 0.145 | 0.021–0.270 | 2.292 | 0.0219 | 79 | 0.101 | LB 0.200 | 38.16 | 0.417 |
| rIFG only | 8 | 0.005 | -0.261–0.271 | 0.037 | 0.9705 | 0 | 0.195 | LB 0.200 | 6.411 | 0.493 |
| Polarity-dependent | | | | | | | | | | |
| Anodal tDCS | 34 | 0.124 | 0.010–0.238 | 2.132 | 0.0330 | 57 | 0.127 | 0.181 | 33.07 | 0.464 |
| dIPFC only | 30 | 0.133 | 0.007–0.460 | 2.069 | 0.0385 | 49 | 0.137 | 0.156 | 29.21 | 0.454 |
| rIFG only | 4 | 0.084 | -0.422–0.589 | 0.325 | 0.7452 | 0 | ¹ | | 2.25 | 0.523 |
| Cathodal tDCS | 12 | 0.073 | -0.231–0.378 | 0.471 | 0.6376 | 0 | 0.162 | LB 0.200 | 11.90 | 0.371 |
| dIPFC only | 8 | 0.168 | -0.297–0.634 | 0.708 | 0.4789 | 0 | 0.129 | LB 0.200 | 7.65 | 0.364 |
| rIFG only | 4 | -0.075 | -0.635–0.486 | -0.263 | 0.7926 | 0 | ¹ | | 3.01 | 0.390 |
| Speed vs Accuracy | | | | | | | | | | |
| Accuracy | 27 | 0.113 | -0.034–0.260 | 1.507 | 0.1319 | 0 | 0.125 | LB 0.200 | 26.88 | 0.415 |
| Speed | 19 | 0.123 | -0.054–0.300 | 1.390 | 0.1645 | 0 | 0.224 | 0.013 | 18.08 | 0.451 |

tDCS = Transcranial Direct Current Stimulation; dIPFC = dorsolateral prefrontal cortex; LB = lower bound; rIFG = right inferior frontal gyrus; \bar{E} = cumulative effect size; CI = Confidence interval; KS = Kolmogorov-Smirnov’s test of normality; Qtotal = total heterogeneity represented by Cohen’s Q; Significant results are highlighted in bold. dIPFC refers to either left dIPFC or bilateral dIPFC (for detailed information refer to Tables 1 and 2 under tDCS montage column). 1KS test could not be performed because of too small sample size

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Table 4. Meta-analysis results for the effects of tDCS on working memory in ADHD patients.

| Cumulative effect size | | | | | | | Normality | | Heterogeneity | |
|------------------------|----|--------------|--------------------|--------------|---------------|------------------|-----------|----------|---------------|---------|
| Analysis | N | \bar{E} | 95% CI | Z | p-value | Fail-safe number | KS test | p-value | Qtotal | p-value |
| Polarity independent | | | | | | | | | | |
| All studies | 18 | 0.150 | -0.226–0.527 | 0.782 | 0.4342 | 0 | 0.121 | LB 0.200 | 17.30 | 0.434 |
| Polarity-dependent | | | | | | | | | | |
| Anodal tDCS | 16 | 0.103 | -0.317–0.523 | 0.481 | 0.6307 | 0 | 0.109 | LB 0.200 | 15.39 | 0.424 |
| Speed vs Accuracy | | | | | | | | | | |
| Accuracy | 11 | -0.192 | -0.672–0.288 | -0.784 | 0.4330 | 0 | 0.160 | LB 0.200 | 10.12 | 0.430 |
| Speed | 7 | 0.659 | 0.173–1.146 | 2.658 | 0.0079 | 16 | 0.141 | LB 0.200 | 5.88 | 0.437 |

tDCS = Transcranial Direct Current Stimulation; \bar{E} = cumulative effect size; CI = Confidence interval; KS = Kolmogorov-Smirnov’s test of normality; Qtotal = total heterogeneity represented by Cohen’s Q; Significant results are highlighted in bold

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Fig 2 has been corrected to reflect the updated results. Please see the corrected Fig 2 here.

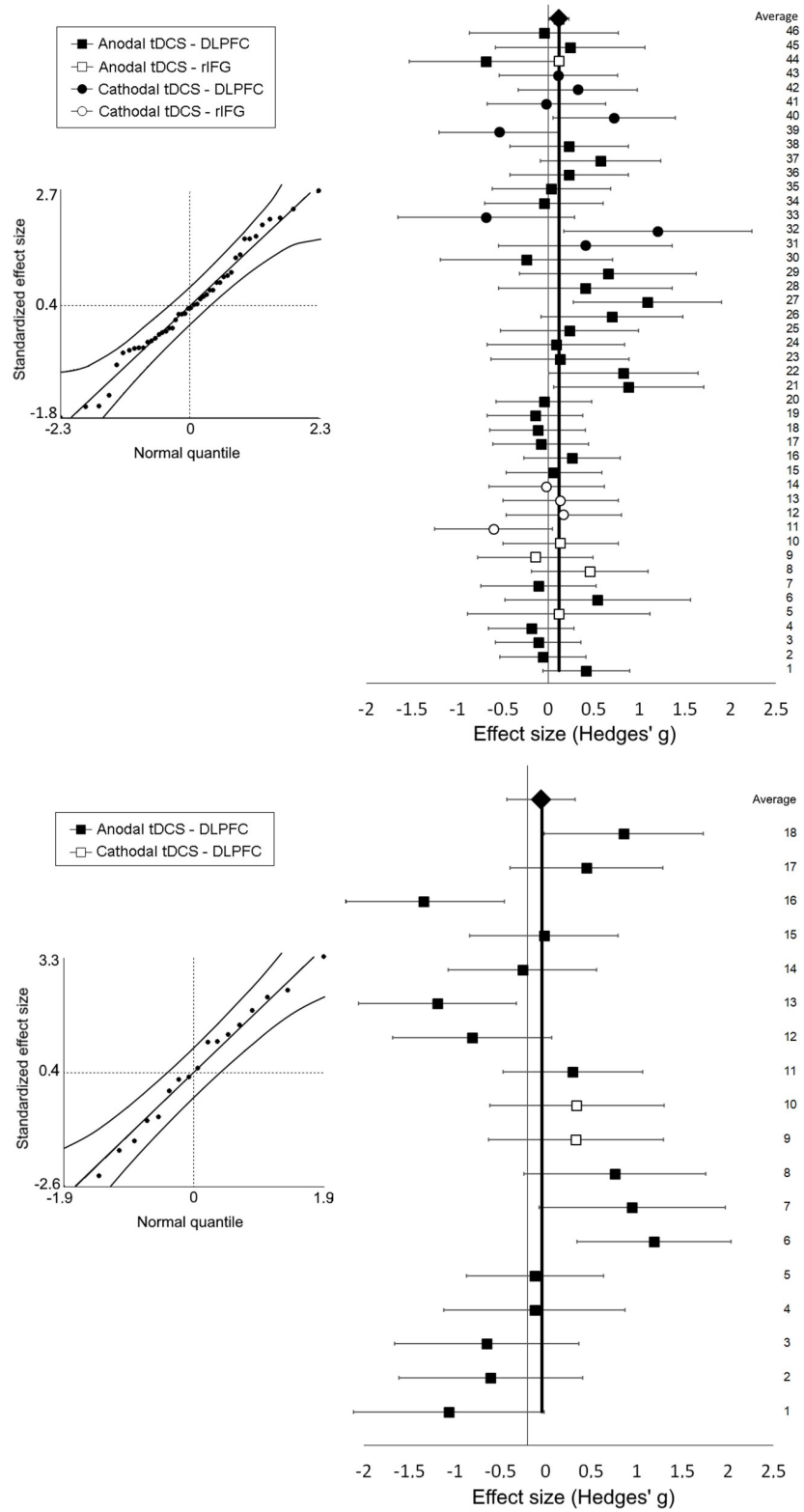


Fig 2. Meta-analysis and forest plot results including Hedges' g and 95% confidence interval and Cumulative effect size of tDCS on inhibitory control (top) and working memory (down).

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In the **Abstract**, there is modification to the seventh and eighth sentences. The correct sentences are: “Additionally, a significant improving effect of tDCS WM speed (but not accuracy) was found with a medium effect size. Overall, this meta-analysis supports a beneficial effect of tDCS on inhibitory control and WM in ADHD with a small effect size.”

In the “*Effects of tDCS on inhibitory control in ADHD patients*” subsection of the **Results**, there are several errors throughout. The corrected “Effects of tDCS on inhibitory control in ADHD patients” subsection is as follows:

“A significant cumulative effect size (\bar{E}) of 0.117 ($Z = 2.10$, $p = 0.035$) was observed for a general tDCS effect on inhibitory control, taking polarity not into account Kolmogorov-Smirnov’s test of normality showed that the distribution of the effect sizes was not significantly different from a normal distribution (lower bound $p = 0.20$) and total heterogeneity of the effect sizes was not significant ($Q_{total} = 46.13$, $p = 0.425$). The fail-safe number indicated that 79 unpublished null-findings would be required to render the effect non-significant. Exploration of montage showed that only dlPFC stimulation (l-dlPFC and bilateral) ($\bar{E} = 0.145$, $Z = 2.29$, $p = 0.021$), but not rIFG stimulation ($\bar{E} = 0.005$, $Z = 0.04$, $p = 0.971$) yielded a significant increase of accuracy rates in inhibitory control task performance.

Subsequently, polarity-dependent effects were investigated. Studies using anodal tDCS showed a significant \bar{E} of 0.124 ($Z = 2.13$, $p = 0.033$), with a fail-safe number of 57 showing that anodal tDCS significantly improved inhibitory control. This sample was distributed normally (lower bound $p = .20$) and showed no significant heterogeneity ($Q_{total} = 33.07$, $p = 0.464$). As for the stimulation polarity-independent analysis, this effect was driven by studies using a left and bilateral dlPFC montage ($\bar{E} = 0.133$, $Z = 2.07$, $p = 0.038$), whereas the rIFG montage did not yield a significant effect ($\bar{E} = 0.084$, $Z = 0.33$, $p = 0.745$). In contrast to anodal tDCS, cathodal tDCS did not show a significant overall effect ($\bar{E} = 0.073$, $Z = 0.47$, $p = 0.637$).

Finally, an analysis was performed separating outcomes measures that focused on accuracy or amount of errors compared to the speed of response. The results showed no significant cumulative effect of tDCS on accurate responses in inhibitory control tasks ($\bar{E} = 0.113$, $Z = 1.51$, $p = 0.131$). No significant cumulative effect was found for speed neither ($\bar{E} = 0.123$, $Z = 1.39$, $p = 0.164$). For this last analysis, a deviation from normality was observed ($p = 0.031$). Results are summarized in [Table 3](#).”

In the “*Effects of tDCS on working memory in ADHD patients*” subsection of the **Results**, there are several errors throughout. The corrected “Effects of tDCS on working memory in ADHD patients” subsection is as follows:

“No significant cumulative effect was observed for tDCS on working memory, without taking polarity into account ($\bar{E} = 0.150$, $Z = 0.78$, $p = 0.434$). Also, no effect of tDCS was observed when only studies with an anodal montage were included ($\bar{E} = 0.103$, $Z = 0.48$, $p = 0.630$). However, when separating outcomes for accuracy and speed, a significant effect of tDCS on speed was observed. TDCS led to a faster response time ($\bar{E} = 0.659$, $Z = 2.65$, $p = 0.008$), with a fail-safe number of 16. The sample was normally distributed (lower bound $p = .20$) and no significant heterogeneity was seen ($Q_{total} = 5.88$, $p = 0.437$). These results should be interpreted with caution, given the low sample size ($N = 7$). Moreover, results showed that tDCS did have no significant effect on accuracy of working memory task performance ($\bar{E} = -0.192$, $Z = -0.78$, $p = 0.433$). Results are shown in [Table 4](#).”

In the **Discussion**, there are errors in the second sentence of the second paragraph (fifth reported results). The correct sentence is: “Further sub-analyses yielded the following findings: (1) tDCS has an overall significant cumulative effect on inhibitory control in ADHD with a small effect size, (2) when the targeted brain region is taken into account, only tDCS over the dlPFC had a significant effect on inhibitory control (small effect size), but not tDCS over the rIFG, (3) when stimulation polarity was taken into account, only anodal, but not cathodal

tDCS had a significant effect on inhibitory control, (4) when both polarity and targeted region are taken into account, only anodal tDCS of the dlPFC had a significant effect on inhibitory control with a small effect size, (5) and when analyzing inhibitory control outcomes separately, tDCS had no significant cumulative effect neither on accuracy, nor speed (i.e., reaction time).”

In the “tDCS effects on inhibitory control in ADHD” subsection of the Discussion, there is an error in the first sentence of the second paragraph. The correct sentence is: “Anodal dlPFC tDCS had the largest effect size (despite of small effect) on inhibitory control in ADHD populations, whereas anodal rIFG tDCS had no significant effect.”

The following sentence is missing from the **Conclusion** subsection: “However it is of note that all of the cumulative significant effect sizes were almost small except the one for effects of tDCS on working memory speed.” The corrected Conclusion subsection is as follows:

“The findings of this meta-analysis of tDCS interventions in ADHD suggest an improvement of neuropsychological deficits (i.e., inhibitory control and WM) by tDCS. Stimulation polarity and target area are relevant for the efficacy of tDCS in ADHD. Anodal dlPFC tDCS had a significantly superior effect on inhibitory control compared to cathodal/sham stimulation and anodal rIFG tDCS. TDCS significantly increased response accuracy of inhibitory control performance and decreased response time in WM tasks. However it is of note that all of the cumulative significant effect sizes were almost small except the one for effects of tDCS on working memory speed. Although our findings suggest improving effects of tDCS in ADHD neuropsychological deficits, the clinical utility of tDCS cannot be firmly rated with the currently available findings. Application of this method as a therapeutic intervention will require optimizing stimulation protocols based on general stimulation parameters and individual and inter-individual factors for improvement of clinical efficacy, exploration of clinical symptoms in addition to surrogate parameters, and achievement of sustained clinical benefits by tDCS over longer durations of time. Thus, future research is needed to more thoroughly explore and refine optimal stimulation parameters required for tDCS-based cognitive improvement and implementing robust experimental designs in different ADHD subtypes. Broadly speaking, the potential for tDCS as a non-invasive brain stimulation technique to safely improve neuroplasticity and treat neurological and neurodevelopmental disorders is encouraging. Future studies utilizing tDCS will further increase our understanding of neural networks and how to treat their pathological states in ADHD and other neurodevelopmental disorders including autism and learning disabilities.”

Reference

1. Salehinejad MA, Wischnewski M, Nejati V, Vicario CM, Nitsche MA (2019) Transcranial direct current stimulation in attention-deficit hyperactivity disorder: A meta-analysis of neuropsychological deficits. *PLoS ONE* 14(4): e0215095. <https://doi.org/10.1371/journal.pone.0215095> PMID: 30978259