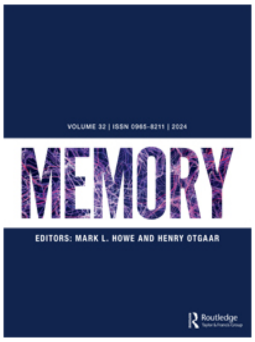

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BRIEF REPORT

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Anodal tDCS of the left inferior parietal cortex enhances memory for correct information without affecting recall of misinformation

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ABSTRACT
False memories during testimony are an enormous challenge for criminal trials. Exposure to post-event misinformation can lead to inadvertent creation of false memories, known as the misinformation effect. We investigated anodal transcranial direct current stimulation (tDCS) on the left inferior parietal lobe (IPL) during recall testing to enhance accurate recall while addressing the misinformation effect. Participants ($N = 60$) watched a television series depicting a fictional terrorist attack, then received an audio recording with misinformation, consistent information, and control information. During cued recall testing, participants received anodal or sham tDCS. Results revealed a robust misinformation effect in both groups, with participants falsely recalling on average 26.6% of the misinformed items. Bayesian statistics indicated substantial evidence in favour of the null hypothesis that there was no difference between groups in the misinformation effect. Regarding correct recall however, the anodal group exhibited significantly improved recall for items from the original video. Together, these results demonstrate that anodal tDCS of the left IPL enhances correct recall of the episodes from the original event without affecting false recall of misinformation. The findings support the IPL's role in recollection and source attribution of episodic memories.

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Misinformation effect; transcranial direct current stimulation; episodic memory; inferior parietal lobe; anodal tDCS

Introduction

Memory accuracy plays a crucial role in the criminal justice system, given that the reliability of eyewitness testimonies can significantly impact legal outcomes. However, the occurrence of false memories presents a considerable challenge in criminal trials. The misinformation effect describes the phenomenon of unintentionally arising false memories after exposure to misleading post-event information (Loftus et al., 1978). Understanding the underlying mechanisms and developing strategies to enhance memory accuracy in the face of misinformation is paramount for ensuring legal justice (Loftus & Klemfuss, 2023). This study aims to investigate whether transcranial brain stimulation can be utilised to pursue the goal of "true memory" enhancement in the light of misinformation in a laboratory setting.

The misinformation effect occurs when individuals are exposed to post-event information that conflicts with their original memory of an event. Misinformation can originate from various sources, including leading questions, suggestive interviews, or exposure to inaccurate details through social media or social interactions (see Loftus, 2005 for a review). Several cognitive factors have been proposed to explain the occurrence of the misinformation effect. One such factor is retroactive interference, where the retrieval of misleading post-event information interferes with the retrieval of the original memory (Belli, 1989). Additional factors include source misattribution and impaired recollection, which refer to the confusion in monitoring between the sources of the original and the misleading information (Belli et al., 1994; Walter & Tukachinsky, 2020). Although the source-monitoring account appears to be one of the most widely accepted explanations of the misinformation effect (see Nichols et al., 2015), alternative explanations for false memories in general exist. For instance, fuzzy trace theory (Brainerd & Reyna, 2002) suggests that episodic memory comprises both verbatim (exact) traces and gist (underlying meaning) traces. In the context of the misinformation effect, individuals may inadvertently incorporate false details into their memory reconstructions, particularly if the misinformation aligns with the gist of the original event.

Recent advancements in transcranial brain stimulation techniques provide a promising avenue to modulate cortical excitability and potentially enhance memory accuracy.

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Table 1. Study demographics.

	n	Age Mean (SD), Range	Sex (m / f / d)	Suspicion (none or incorrect / correct)	Familiarity (familiar / not familiar)
Anodal group	30	23.13 (3.95), 18–34	7 / 23 / 0	19 / 11	2 / 28
Sham group	30	23.13 (5.42), 18–48	4 / 25 / 1	21 / 9	1 / 29
Total sample	60	23.13 (4.70), 18–48	11 / 48 / 1	40 / 20	3 / 57

Note: Demographics are listed for the anodal stimulation group, the sham stimulation group, and the total study sample. Gender is reported as male (m), female (f), and diverse (d). Prior knowledge refers to participants reporting correct suspicion regarding the misinformation effect. Familiarity refers to whether participants reported that they have watched the TV series “24” prior to study participation. Removal of the three participants who were familiar with the television series “24” did not significantly impact any of the reported results.

Transcranial Direct Current Stimulation (tDCS) is one such technique allowing the targeted modulation of cortical activity by applying weak electrical currents to specific brain regions on the scalp (Woods et al., 2016). Anodal tDCS, known for enhancing cortical excitability, has shown potential in influencing episodic memory processes. For instance, during the encoding of face-name associations, the application of anodal tDCS to the left frontal cortex significantly improved associative memory in recall tasks, with no observed effect in recognition tasks (Leshikar et al., 2017; Matzen et al., 2015). This selective impact on retrieval tasks was confirmed in a recent meta-analysis by Galli et al. (2019), suggesting that anodal tDCS may specifically enhance the recollection process in episodic memory. Considering the left parietal cortex’s role in recollection during recall tasks (Vilberg & Rugg, 2008), our present study aimed to stimulate the left inferior parietal lobule (IPL) during recall testing, exploring the effects of anodal tDCS on memory accuracy and confidence.

While recent research has begun to explore the effects of tDCS on the creation of false memories, our understanding of how tDCS influences the misinformation effect is limited. Previous studies have delved into the effects of tDCS on false memories in the Deese-Roediger-McDermott (DRM; Deese, 1959; Roediger & McDermott, 1995) task (Boggio et al., 2009; Friehs et al., 2021b; Pergolizzi & Chua, 2015). However, DRM false memories and the misinformation effect typically involve distinct mechanisms (Calvillo & Parong, 2016; Ost et al., 2013; Zhu et al., 2013). Unlike false memories in the DRM task, the potential effects of tDCS on the misinformation effect remain largely unexplored. Therefore, there is an urgent need to investigate and analyze the potential benefits of applying tDCS in misinformation settings.

The present study explores the influence of anodal tDCS, applied to the left IPL during recall testing, comparing it to sham stimulation, on correct recall, the misinformation effect, and memory confidence. We posit that the left IPL is a critical region to examine the effects of stimulation on memory processes. The left IPL has been suggested to be involved in the recollection and source monitoring of episodic memories (Vilberg & Rugg, 2008). Specifically, the angular gyrus has been proposed as a binding structure, facilitating the integration of distributed information in the brain into cohesive episodic memories (Rugg & King, 2018). Alternative to this representational view of IPL function, the left IPL has been associated with bottom-up attention (Cabeza et al., 2012) and the buffering of multisensory and spatiotemporal information (Humphreys et al., 2021), suggesting functional heterogeneity within this brain area.

Following the view that the left IPL is implicated in recollection during recall tasks, we hypothesised that anodal tDCS applied to the left IPL will enhance correct recall of the originally experienced event without affecting or even reducing the misinformation effect in participants. To examine this hypothesis, we implemented a three-stage procedure. Participants initially viewed a video depicting a fictional terrorist attack. Subsequently, participants listened to an audio recording summarising the video. This audio recording included misinformation, consistent information, and control information. Finally, a cued recall test was administered, prompting participants to recall specific episodes from the original video. The choice of a cued recall test aimed to ensure a controlled and reliable measurement of recall for all three types of items. Additionally, utilising cued recall helped mitigate potential output order effects inherent in free recall scenarios. We explored the effects of anodal tDCS versus sham stimulation during the final cued recall testing, assessing both recall accuracy and memory confidence. If active stimulation of the left parietal cortex enhances true memories without affecting or reducing false memories, this would support the recollection view of the misinformation effect and potentially offer a tool to enhance memory accuracy in the context of misinformation.

Materials and methods

Participants

Sixty students from the University of Trier, Germany, participated in the study (11 male, 48 female, 1 diverse, mean age = 23.13 years, $SD = 4.70$ years; demographics per stimulation group are presented in Table 1). One additional participant excluded from the analysis due to an incorrect experimental procedure. The effect sizes for the misinformation effect observed in previous studies were large (Chan et al., 2009; Chan & Langley, 2011). In a pilot study with $N = 10$ participants, utilising study materials translated to German from Chan and Langley (2011), we successfully replicated a robust misinformation effect, $t(9) = 5.50$, $p < .001$, Cohen’s $d = 1.74$. Concerning the anticipated influence of stimulation on correct recall of the original episodes, measured separately in the misinformation, consistent, and control conditions, we expected a small-to-medium effect for the within-between interaction (Minarik et al., 2016). With $\alpha = .05$, a power of $1 - \beta = .95$, and a correlation among repeated measures of $r = .30$, a small-sized or larger effect of $f \geq .25$ could be detected with $N = 60$ participants in a within-between repeated measures ANOVA (G*Power 3.1.9; Faul et al., 2007).

All participants reported normal or corrected-to-normal vision. Exclusion criteria referred to subjective reports of conductive metal around the scalp (e.g., piercings, tattoos), neurological, psychiatric, cardiovascular, or skin diseases (e.g., migraine, epilepsy, aneurysm), pregnancy, alcohol intoxication, or medication intake (e.g., antidepressants, benzodiazepine, thyroid drugs). All participants gave written informed consent before the examination and received course credit or monetary compensation (15€) for participation (this factor showed no significant influence on any of the present results). We did not collect specific data on participants' handedness. The study was conducted in accordance with the Declaration of Helsinki and approved by the local ethics review committee at the University Trier (Reference Number: UT21-KA-004).

Design

The experimental design was adopted from Chan and Langley (2011), who employed an applied misinformation paradigm based on the first episode from the television series "24". The video content was condensed into an audio recording, encompassing misinformation, consistent information, and control information items. Participants' responses in the cued-recall test were categorised as either correct, wrong, "don't know, or misinformed intrusion, depending on their performance. During recall testing, anodal tDCS was applied to the left IPL for 10 min in half of the participants. The remaining participants underwent sham stimulation for the same duration. Consequently, the current experimental design employed a 3×2 mixed-design, incorporating the within-subjects factor of condition (misinformation vs. consistent vs. control) and the between-subjects factor of tDCS (anodal vs. sham).

Stimulus materials and procedure

The stimulus material was adapted from Chan et al. (2009), featuring the television series "24". Both the video content and the questions for the memory test were translated into German. The validity of the translated study material, as well as the misinformation effect, was confirmed in a pilot study with $N = 10$ participants who were subsequently excluded from participation in the present study.

After arriving at the laboratory, participants underwent a check for inclusion criteria and provided informed written consent (see Figure 1 for an overview of the study procedure). Participants were instructed to carefully watch the video recording for an upcoming memory test. Subsequently, the first episode of the television series "24", lasting 30 min, was shown. Following this, the tDCS electrodes were positioned (see below). To introduce a distractor task, a 10-minute reportage about police investigations (Polizei NRW, 2021) was presented. Following the distractor, one of three randomly selected audio summaries (A, B, or C) of the video was presented. Each audio recording included statements categorised as consistent ("consistent", e.g., "Her mother left her 5 messages on her cell phone".), misleading ("misinformation", e.g., "Her mother left her 7 messages on her cell phone".), non-informative ("control", e.g., "Her mother left her messages on her cell phone".). All but one item (due to an assignment error in audio version B) were counterbalanced across the three conditions (misinformation, consistent, control) in the three audio versions A, B, and C. Audio files A and C both consisted of 8 misinformed, 8 consistent, and 8 control items, whereas audio file B consisted of 9 misinformed, 7 consistent, and 8 control items. Following this phase, participants engaged in a 5-minute Sudoku activity to prevent rumination on the audio summaries. The subsequent cued recall test directed participants to recall information specifically from the original "24" video and not from the audio recording. Online stimulation commenced at the beginning of the cued recall test.

During the cued recall test, participants faced 24 questions related to the previously summarised consistent, control, and misinformation items from the video (e.g., "How many messages does Kim have on her phone?"). These questions were presented in a randomised order, and participants were instructed to respond in a free-text field using a QWERTZ keyboard. Subsequent to providing their answers, participants used the mouse to rate their confidence in remembering each answer on a scale from 0 ("I don't remember at all".) to 100 ("I remember for sure".) in increments of 1. Each question had a response and confidence rating time limit of 21 s, after which participants proceeded to the next question. The mean overall recall time for the 24 questions was 9 min and 51 sec in the anodal group and 9 min and 48 sec in the sham group, $t(58) < 1$. Following the cued recall test, participants indicated whether they had an idea about the experimental hypotheses (e.g., suspicion regarding the misinformation effect) and whether they had previously watched the television series "24" (see Table 1 for the results). Additionally, participants were asked about any side effects of tDCS in a questionnaire. Finally, participants were thanked and debriefed. Presentation and recording of recall answers were done with PsychoPy software (version 2022.1.1, Open Science Tools Ltd).

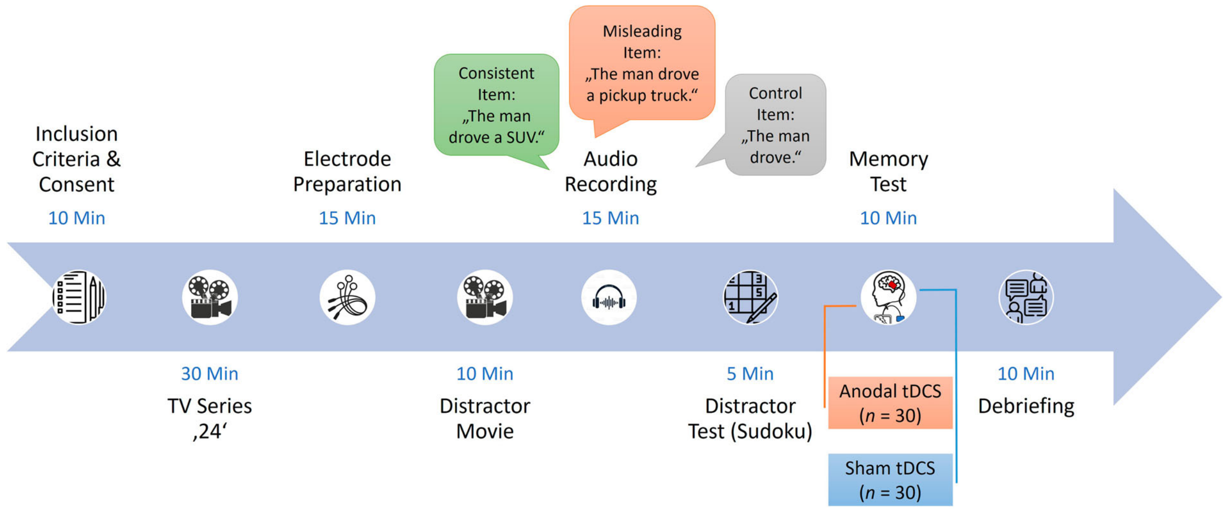

Figure 1. Overview of the study procedure over time. After arrival, participants were checked for inclusion criteria and gave written informed consent. They watched 30 min of the first episode of the television series "24". Electrodes were placed and impedance was checked. After a distractor video about police investigations, participants listened to one of three audio versions (A, B, or C), which contained a summary of consistent, misleading, and control statements of the original "24" video. After a distractive Sudoku test, participants gave free-text answers to 24 questions about the original "24" video in a cued-recall memory test. During the memory test, either anodal or sham tDCS was applied. Finally, participants were asked for side effects of the tDCS, thanked, and debriefed.

Transcranial direct current stimulation (tDCS)

Direct current was applied by a four-channel constant current generator (DC-STIMULATOR by NeuroConn, Ilmenau, Germany). In all stimulation conditions, a 9 cm^2 (3 × 3 cm) electrode was positioned over the left IPC (corresponding to BA 39 and BA 40 at the CP5 position according to the 10–20 EEG electrode system; Chatrian et al., 1988), and a 35 cm^2 (5 × 7 cm) reference electrode was placed on the left deltoid muscle over the upper arm. Half of the participants were in the anodal tDCS group, and the other half were in the sham group. In the anodal tDCS group, a current of 0.5 mA was applied for 9 min with an additional 30 sec ramp-up phase at the beginning and a 30 sec ramp-down phase at the end of the stimulation, thus totalling 10 min of stimulation time. In the sham condition, the ramp-up/ramp-down phase was included both at the start and the end of the supposed stimulation period, with 8 min of no stimulation time in between. The stimulation was controlled via a panel PC.

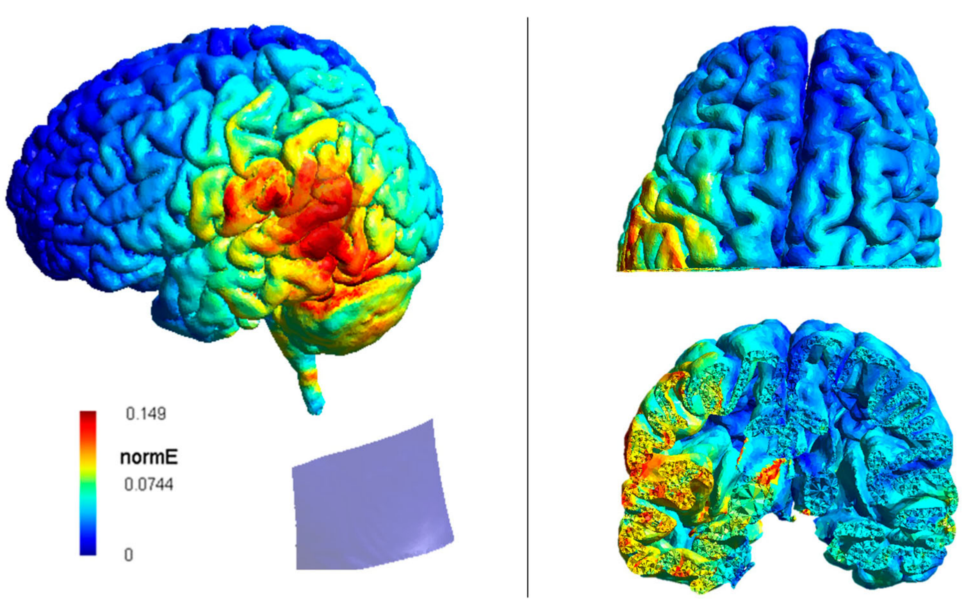

Figure 2. Left: Whole brain simulation of the current flow for a 3 × 3 cm^2 anode (displayed in red; CP5-position) and cathode (displayed in blue) over the left upper shoulder area. Right: Sliced brain images at the coronal plane at the peak stimulation intensity of the anode. Peak stimulation intensities were reached in the cortical areas and little current is expected to flow through the brain into subcortical areas such as the hippocampus. normE: Magnitude of the electric field (V/m). Simulation performed with SimaNIBS (Saturnino et al., 2018).

Current flow patterns over the stimulated brain regions were validated by using the software HD-Explore (Soterix Medical Inc., New York, NY). Current flow patterns were simulated using the SimNIBS software (Saturnino et al., 2018). Figure 2 depicts the calculated current flow.

Notably, we opted for 10 min of stimulation to balance efficacy and participant comfort. The choice of a .5 mA current strength was informed by successful applications in similar setups impacting response inhibition and working memory, as supported by existing literature (Friehs & Frings, 2019a, 2019b; Friehs et al., 2021a). The selection of CP5 as the stimulation site was driven by our focus on recollection/source attribution as a process candidate for the misinformation effect, aligning with left parietal brain activation commonly associated with recollection in EEG research. Regarding the decision to stimulate during retrieval instead of encoding, our interest in the practical application of tDCS in real-life observations of crime events influenced this choice. The feasibility of applying tDCS during encoding in such scenarios is limited, making retrieval a more practical and applicable target for our investigation.

Statistical analyses

Participants' recall performance was assessed independently by three trained raters. The raters were instructed to rate the answers per condition (misinformation, consistent, control) and per answer category (correct, wrong, don ´t know, misinformed intrusion) for the recalled answers as well as for the confidence ratings.

Krippendorffs alpha values for ordinal-scaled data were reported with 95% confidence intervals separately for each condition and answer category. Krippendorff's alpha for the recalled answers in the memory test ranged between a minimum of $\alpha = 0.81$, 95% CI [0.69, 0.88] for wrong answers in the misinformation condition, and a maximum of $\alpha = 0.99$, 95% CI [0.97, 1.00] for "don't know" answers in the consistent condition (see Table 2 for the rater agreement for the recalled answers). The rater agreements suggest "reliable values" (0.80−1.00) according to Krippendorff (1998). Rater agreement of the confidence ratings suggest overall "reliable values" according to Krippendorff (1998) except for misleading intrusions and "don't know" answers (range from $\alpha = 0.74$ to $\alpha = 0.76$), which is still acceptable for "tentative conclusions" (see Table 3 for the rater agreement for the confidence ratings). To increase the reliability of recall measures, the averaged ratings were used for all analyses of recall data.

Regarding testing of a-priori hypotheses, repeated-measures ANOVAs with the within-factor condition (misinformation vs. consistent vs. control), and the between-factor tDCS (anodal vs. sham) were calculated for correct recall and confidence ratings. Greenhouse-Geisser correction was applied where appropriate. Post-hoc tests are reported with Holm-corrected *p* values, (p_{holm}). Regarding the misinformation effect, the number of misleading intrusions was compared between tDCS conditions in an independent samples *t*-test; in addition, one-sample *t*-tests (against 0) were calculated for the two groups. In addition, confidence ratings for the misleading intrusions were compared between stimulation conditions with an independent samples *t*-test. Significant results in null-hypothesis tests are reported with appropriate effect sizes, whereas non-significant results are specified by Bayes Factor BF_{01} (or BF_{excl} for interaction effects across matched models), which quantifies the relative support in the observed data for the *H0* over the *H1,* assuming a uniform prior distribution on the correlation parameter Pearson's ρ (Hoijtink et al., 2019).

In conclusion, additional exploratory frequentist ANOVAs were conducted to investigate the potential impact of participants' gender (male vs. female) and suspicion levels (suspicious vs. not suspicious) regarding the misinformation effect. Participants were queried about their awareness of the experiment's focus on the misinformation effect following the cued recall test. Note that the "diverse" category of gender was not included in these

Table 2. Rater agreement for recall performance.

Condition	Recall Responses	Krippendorff's Alpha	95% Confidence Interval Lower CI – Upper CI
Misinformation	Misinformed intrusions	0.91	0.83–0.96
	Correct	0.93	0.87–0.98
	Wrong	0.82	0.70–0.89
	Don't know	0.94	0.88–0.98
Consistent	Correct	0.90	0.81–0.95
	Wrong	0.85	0.74–0.92
	Don't know	0.99	0.97–1.00
Control	Correct	0.92	0.86–0.95
	Wrong	0.82	0.69–0.90
	Don't know	0.95	0.90–0.98

Note: Krippendorff's alpha was calculated for ordinal-scaled data. Krippendorff's alpha can be interpreted as: 0.80–1.00 are reliable values; 0.67–0.79 are acceptable for tentative conclusions, 0.00–0.66 are not acceptable (Krippendorff, 1998). Confidence intervals are based on percentiles from 1,000 bootstrap replications.

Table 3. Rater agreement for the confidence ratings.

Condition	Recall Responses	Krippendorff's Alpha	95% Confidence Interval Lower CI – Upper CI
Misinformation	Misinformed intrusions	0.76	0.52–0.93
	Correct	0.80	0.60–0.96
	Wrong	0.81	0.57–0.95
	Don't know	0.76	0.45–0.98
Consistent	Correct	0.94	0.86–0.98
	Wrong	0.92	0.81–0.99
	Don't know	0.92	0.81–1.00
Control	Correct	0.81	0.66–0.92
	Wrong	0.83	0.62–0.95
	Don't know	0.74	0.51–0.92

Note: Krippendorff's alpha is calculated for ordinal-scaled data. Krippendorff's alpha can be interpreted as: 0.80–1.00 are reliable values; 0.67–0.79 are acceptable for tentative conclusions, 0.00–0.66 are not acceptable (Krippendorff, 1998). Confidence intervals are based on percentiles from 1,000 bootstrap replications.

additional analyses due to empty cells in the design. Notably, it is important to interpret the results of all additional analyses with caution, considering the unbalanced designs and relatively small statistical power for higher-order interactions. All data were analysed with JASP software (version 0.18.1; JASP Team, 2023).

Results

Correct recall

A repeated-measures ANOVA for the correct answers with the within-subjects factor condition (misinformation vs. consistent vs. control) and the between-subjects factor tDCS (anodal vs. sham) revealed a significant main effect of condition, $F(2, 116) = 51.16$, $p < .001$, $\eta_p^2 = .469$, and also a significant main effect of stimulation, $F(1, 58) = 6.66$, $p = .012$, $\eta_p^2 = .103$. The interaction between the two factors was not significant, $F(2, 116) < 1$, $BF_{excl} = 7.98$. Regarding the main effect of condition, the correct recall was enhanced in the consistent condition (62.5%) and impaired in the misinformation condition (35.3%) in comparison to the control condition (47.7%); all three pair-wise comparisons between conditions were significant, all $ps_{holm} < .001$. More importantly, regarding the main effect of stimulation, anodal tDCS of the left inferior parietal cortex increased correct recall in comparison to the sham stimulation (51.9% vs. 45.1%; see Figure 3(A), Table 4). Additional exploratory analyses, incorporating the factors of gender (male vs. female) and suspicion (suspicious vs. not suspicious) into the ANOVA design, revealed no significant main effects or interactions involving these factors, *all ps* $> .05$.

Misinformation effect

The misinformation effect was present in both groups. Indeed, the number of misleading intrusions was significantly larger than 0 in both the anodal tDCS group (25.4%), $t(29) = 10.01$, $p < .001$, $d = 1.83$, and the sham group (27.8%), $t(29) = 10.18$, $p < .001$, $d = 1.86$. Importantly, the number of misleading intrusions did not differ significantly between stimulation groups, $t(58) < 1$, $BF_{01} = 3.19$ (Figure 3(B); see Table 4). Additional exploratory 2 (tDCS) × 2 (gender) and 2 (tDCS) × 2 (suspicion) ANOVAs revealed no significant main effects or interactions involving the factors of gender or suspicion, *all ps* $> .05$.

Table 4. Descriptive values (percent correct) for the recall responses.

tDCS	Condition	Recall Responses	Mean	SE
Anodal	Misinformation	Misinformed intrusions	**25.4**	**2.5**
		Correct	**39.2**	**2.6**
		Wrong	17.1	1.8
		Don't know	18.3	2.4
	Consistent	Correct	**64.8**	**3.5**
		Wrong	21.9	3.1
		Don't know	13.3	2.3
	Control	Correct	**51.7**	**2.8**
		Wrong	28.3	2.7
		Don't know	20.0	2.7
Sham	Misinformation	Misinformed intrusions	**27.8**	**2.7**
		Correct	**31.3**	**2.6**
		Wrong	21.4	2.5
		Don't know	19.4	2.9
	Consistent	Correct	**60.3**	**2.8**
		Wrong	20.5	2.2
		Don't know	19.2	2.2
	Control	Correct	**43.8**	**2.8**
		Wrong	33.1	2.5
		Don't know	23.1	2.8

Note: Means and standard errors (SE) of the means for the recall responses (in percent). The values written in bold were included in the inferential statistical analyses.

Confidence ratings

Regarding correct recall, a repeated-measures ANOVA for the confidence ratings of correct responses with the factors of condition (misinformation vs. consistent

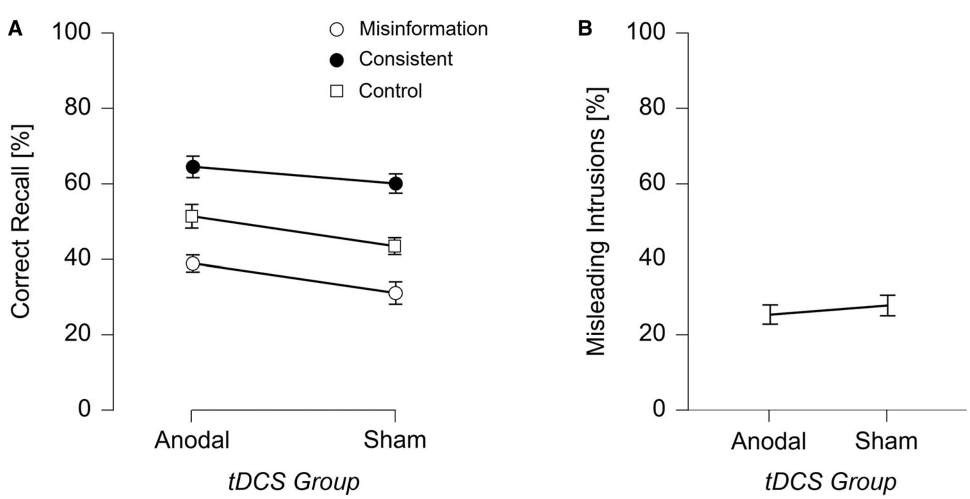

Figure 3. Recall results. (A) Correct recall in percent as a function of condition (misinformation, consistent, control) and stimulation (anodal, sham). (B) The number of misleading intrusions in the anodal and sham tDCS groups. Error bars show standard errors of the mean.

vs. control) and tDCS (anodal vs. sham) showed no significant main effect of condition, $F(2,\ 116) = 1.55$, $p = .219$, $BF_{01} = 1.38$, no significant main effect of stimulation, $F(1,\ 58) < 1$, $BF_{01} = 3.76$, and no significant interaction, $F(2,\ 116) < 1$, $BF_{excl} = 3.35$ (see Table 5). Additional exploratory analyses, incorporating the factors of gender (male vs. female) and suspicion (suspicious vs. not suspicious) into the ANOVA design, revealed no significant main effects or interactions involving these factors, *all ps* $> .05$.

Regarding false recall, the confidence ratings for misleading intrusions did not differ significantly between groups, $t(58) = -1.96$ (anodal minus sham), $p = .054$, $BF_{01} = 0.77$. The additional exploratory 2 (tDCS) × 2 (gender) ANOVA revealed no significant main effect or interaction involving the factor of gender, both $ps > .05$. However, the 2 (tDCS) × 2 (suspicion) ANOVA revealed a significant main of suspicion, $F(1,\ 56) = 7.14$, $p = .010$, $\eta_p^2 = .113$, while the interaction between tDCS and suspicion was not significant, $F(1,\ 56) = 1.19$, $p = .280$. Indeed, the suspicious participants showed overall lower recall ratings for misleading intrusions (41.2) than the not-suspicious participants (59.9).

Discussion

The results of this study demonstrate that anodal tDCS of the left IPL increases the correct recall of true memories without affecting the occurrence of false memories, known as the misinformation effect. Confidence ratings for both true and false memories did not significantly differ between the active and sham stimulation conditions, indicating a dissociation between objective (recall) and subjective (confidence) memory effects. The recall findings align with previous research that has shown beneficial effects of tDCS on correct recall performance when applied to various brain regions, including frontal and parietal sites (e.g., Leshikar et al., 2017; Westphal et al., 2019; see meta-analysis by Galli et al., 2019). However, regarding false memories, the results do not provide significant evidence against the null hypothesis that there is no difference in the misinformation effect between anodal and sham stimulation. Indeed, Bayesian analysis suggests substantial evidence in favour of the null hypothesis, indicating that the stimulation may not significantly impact the occurrence of false memories. Future research could explore other brain stimulation approaches, such as cathodal tDCS, to examine potential counter-directional effects on memory accuracy. While our current stimulation setup makes it unlikely that subcortical regions crucial for memory functions, such as the hippocampus, were significantly influenced, it is important to note that studies, like Nikolin et al. (2015), suggest the potential for hippocampal stimulation with different configurations. Future investigations may choose to target alternative (subcortical) regions to explore various memory processes implicated in the formation and retrieval of false memories (see, for instance, Nikolin et al., 2015).

Table 5. Descriptive values for the confidence ratings.

tDCS	Condition	Recall Responses	Mean	SE
Anodal	Misinformation	Misinformed intrusions	**47.1**	**4.7**
		Correct	**74.8**	**3.9**
		Wrong	49.4	5.3
	Consistent	Correct	**77.5**	**2.8**
		Wrong	36.3	4.9
	Control	Correct	**74.5**	**2.9**
		Wrong	44.7	5.4
Sham	Misinformation	Misinformed intrusions	**60.3**	**4.8**
		Correct	**72.5**	**4.3**
		Wrong	37.3	5.3
	Consistent	Correct	**78.7**	**3.0**
		Wrong	34.2	4.6
	Control	Correct	**71.5**	**3.5**
		Wrong	47.2	5.4

Note: Means and standard errors (SE) of the means for the confidence ratings (ranging from 0 to 100). The values written in bold were included in the inferential statistical analyses.

Regarding correct recall, we observed consistent benefits of anodal stimulation on correct recall, irrespective of whether the correct information was repeated, replaced by misinformation, or not explicitly referred to in the audio recording. This robust enhancement in recall performance suggests that, independent of stimulation conditions, repetition enhancement plays a crucial role in improving memory retrieval. Our findings align with the source attribution account of the misinformation effect, implicating the left IPL in recollection during recall and recognition tasks (Vilberg & Rugg, 2008). While our results support the idea of source misattribution and impaired recollection, they do not speak against other potentially relevant explanations of false memories and the misinformation effect (e.g., fuzzy trace theory; Brainerd & Reyna, 2002). The left IPL, particularly the angular gyrus, has been proposed to function as a binding structure, facilitating the integration of distributed information into cohesive episodic memories (Rugg & King, 2018). However, it is essential to acknowledge the functional heterogeneity within the left IPL, as it has also been linked to bottom-up attention and the buffering of multisensory and spatiotemporal information (Cabeza et al., 2012; Humphreys et al., 2021). An alternative interpretation of our results could be related to attention-to-memory processes in the posterior temporal lobe or supramarginal gyrus, rather than relying solely on recollection associated with the angular gyrus. This alternative explanation aligns with previous research highlighting the role of attention in memory processes (Cabeza et al., 2012). Future studies exploring the specific contributions of different regions within the IPL and their interactions with attention networks could provide a more nuanced understanding of the mechanisms underlying the observed memory enhancement effects of tDCS.

While the observed improvement in memory recall may seem modest on an individual basis, it is crucial to recognise the potential cumulative impact, especially in forensic or legal contexts. Even a one or two-trial improvement in recall, when aggregated across multiple individuals, could contribute to a more comprehensive and accurate account of events. The nature of legal cases often involves the accumulation of evidence from multiple witnesses, and the cumulative effect of improved memory across several individuals could lead to a more robust and reliable overall testimony. Furthermore, in legal proceedings, where details can be pivotal, even a slight enhancement in recall accuracy can be of substantial importance. It is important, however, to acknowledge the limitations of our methodology and the associated challenges in applying it to the applied field. In fact, the controlled environment of our laboratory study does not fully capture the complex and dynamic nature of real-world situations encountered in forensic or legal contexts, raising concerns about the practical applicability of our results in such settings.

Regarding false recall, a robust misinformation effect was observed in both the anodal stimulation and the sham group, with participants falsely recalling an average of 26.6% of the misinformed items from the audio recording instead of remembering the original information from the video. While the misinformation effect did not significantly differ between the stimulation groups, strategies such as providing warnings before recall testing could be employed to reduce the occurrence of misleading intrusions. Warnings given before recall or recognition tasks have been shown to effectively help individuals resist the influence of misinformation and enhance memory accuracy (Blank & Launay, 2014; Dodd & Bradshaw, 1980; Greene et al., 1982; Wright, 1993). Combining brain stimulation with warnings during final recall testing could be a promising approach to enhance true recall and reduce false memories. This possibility warrants investigation in future research.

In terms of practical implications, tDCS may be considered as a strategy to selectively enhance correct memory in more applied settings (e.g., eyewitness memory). However, as noted above, the limitations of our methodology in a laboratory setting and the associated challenges in applying it to the applied field need to be acknowledged. In addition, ethical considerations should be considered, as the use of tDCS may raise concerns about intrusiveness and manipulation. Additionally, the potential risks and long-term effects of tDCS on individuals should be carefully evaluated. It is important to acknowledge that individual responses to stimulation may vary, and while tDCS may benefit the correct recall of some individuals, it could potentially hinder recall in others. Before the application of tDCS there is no way of knowing the exact outcome of the stimulation for a specific individual and thus wrongfully applied stimulation could result in more, not less, false memories (for a discussion about the neurophysiological basis see Bergmann & Hartwigsen, 2021, and Friehs et al., 2021a, for demonstrative results). Lastly, the complex nature of human memory and cognition makes it challenging to isolate specific cognitive functions, and there is a risk that tDCS may inadvertently impact other aspects of cognition relevant to accurate testimony.

In conclusion, this study demonstrates that anodal tDCS of the left IPL enhances the correct recall of true memories without significantly affecting the occurrence of false memories in the misinformation effect. Moreover, the results of the confidence ratings suggest that participants were unaware of the enhancement effect of the stimulation on true memory recall. Together, these findings provide valuable insights into the potential application of tDCS in improving memory accuracy. Further research is needed to explore alternative stimulation approaches and investigate the combined effects of tDCS and warning strategies. Overall, this study contributes to our understanding of the complex interplay between brain stimulation, memory processes, and the reliability of episodic memory recall.

Open Scholarship

This article has earned the Center for Open Science badge for Open Data. The data are openly accessible at https://osf.io/ugtbw/.

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