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Common and distinct contributions of the dorsomedial prefrontal and posterior parietal cortices to social episodic memory

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Abstract

The self-reference effect (SRE) refers to the robust mnemonic advantage for self-relevant information and is characterised by a graded pattern spanning the self, close others, and distant others. Despite extensive behavioural evidence, causal evidence for the neural mechanisms supporting the SRE remains limited, particularly during incidental encoding and across source memory, metacognition, and emotional valence. We investigated the causal contributions of the dorsomedial prefrontal cortex (dmPFC) and posterior parietal cortex (PPC) to self–other episodic memory and metacognition using focal transcranial direct current stimulation (tDCS). One hundred participants completed an incidental encoding task in which trait adjectives were rated with reference to the self, a close friend, or a celebrity, under anodal or sham stimulation to either region. Recognition tests assessed item and source memory sensitivity (d') and metacognitive efficiency (meta-d'/d') as a function of agent and emotional valence. Across stimulation conditions, a graded advantage for self-related information was observed in both item and source memory, extending to metacognitive efficiency. Anodal stimulation to either region attenuated the self-reference effect. PPC stimulation additionally biased source memory away from positive and towards negative information. These findings demonstrate shared and dissociable causal roles of dmPFC and PPC in self–other episodic memory.

Keywords: self-reference effect, source memory, item memory, metacognition, self-other processing, transcranial direct current stimulation (tDCS)

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Humans exhibit systematic self-biases in cognitive processing, one prominent example being the self-reference effect (SRE) in episodic memory. The SRE refers to the reliable enhancement of memory for self-relevant information relative to information encoded in other, non-self-referential contexts (Symons & Johnson, 1997). This advantage is commonly attributed to deeper and more elaborative encoding of self-relevant material, which benefits from integration with rich, well-established self-related knowledge structures (Conway, 2005). Importantly, the magnitude of the SRE is not categorical but graded as a function of social closeness. Memory performance is typically strongest for self-referenced information, intermediate for information related to close others, and weakest for information associated with socially distant individuals such as celebrities (Kokici et al., 2023). Despite substantial behavioural evidence for the self-reference effect, causal evidence for its neural substrates remains limited. Here, we used focal transcranial direct current stimulation targeting the dorsomedial prefrontal cortex and posterior parietal cortex to test their roles in graded self–other episodic memory.

The medial prefrontal cortex (mPFC) is a core region of the social brain implicated in the processing of both self- and other-relevant information (Courtney & Meyer, 2020; Denny et al., 2012), as well as in episodic memory encoding and retrieval (Euston et al., 2012). Neuroimaging studies suggest a ventral-to-dorsal functional gradient within the mPFC, whereby ventral regions are preferentially engaged during self-referential processing, while more dorsal regions are recruited during other-referential processing (Denny et al., 2012). Consistent with this account, causal evidence from non-invasive brain stimulation indicates that focal transcranial direct current stimulation to the dorsomedial prefrontal cortex (dmPFC) selectively enhances

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recognition for other-relevant, but not self-relevant, information (Martin, Huang, et al., 2019; Martin, Su, et al., 2019). However, these studies employed intentional encoding with an expected memory test, raising the possibility that executive control processes were disproportionately engaged, potentially inflating prefrontal contributions to memory performance (Kensinger & Ford, 2021). Moreover, prior stimulation work has focused primarily on the self and socially distant others, despite evidence that close others occupy a distinct and potentially intermediate representational space in the mPFC (Courtney & Meyer, 2020).

The posterior parietal cortex (PPC) is often associated with attentional orienting, perceptual processing, and sensorimotor integration (Corbetta & Shulman, 2011), but it is also increasingly recognised as a key contributor to episodic memory encoding, consolidation, and retrieval (Berryhill, 2012; Sestieri et al., 2017). Brain stimulation studies targeting the PPC have yielded mixed effects on memory performance, with some reports demonstrating modulation of associative memory (Meng et al., 2021; Vulić et al., 2021) and others observing null effects (Dubravac et al., 2021; Rossi et al., 2006). Notably, the medial parietal cortex, a subregion within the broader PPC, has been implicated in self- and other-referential memory retrieval, showing a graded pattern of activation that is strongest for the self, intermediate for close others, and weakest for public figures (Lou et al., 2004). Moreover, disruption of medial parietal activity using transcranial magnetic stimulation selectively impairs self-referential memory retrieval (Lou et al., 2004). Beyond episodic memory, converging evidence suggests that the PPC plays a broader role in representing social space, mapping relationships between the self and others in a manner analogous to its role in representing physical space (Yamakawa et al., 2009). Together, these

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findings suggest that the PPC contributes not only to memory processes but also to the self–other distinctions that underpin social cognition.

An important component that has received relatively little attention in research on the self-reference effect is metamemory, or metacognition about memory, defined as the ability to monitor and evaluate one's own memory performance (Dunlosky & Thiede, 2013). Although self-biases are well established across core cognitive domains including memory, attention, and perception (Amodeo et al., 2021; Nijhof et al., 2020), it remains unclear whether these biases extend to higher-order processes such as metacognitive awareness of memory. Neurocognitive models of metacognition implicate distributed frontoparietal systems, including medial prefrontal and posterior parietal regions that overlap with networks supporting self-referential processing and episodic memory (Fleming & Dolan, 2012). Kokici and colleagues (2023) addressed this question by applying signal detection theoretic measures to examine whether the graded self–other pattern observed in memory performance is also evident in metamemory. Specifically, they quantified metacognitive sensitivity (meta-d'), which reflects how effectively confidence judgements distinguish between correct and incorrect memory decisions. Because meta-d' is constrained by first-order memory sensitivity (d'), metacognitive efficiency, defined as the ratio of meta-d' to d', was also calculated to isolate metacognitive performance independently of memory accuracy (Fleming & Lau, 2014). Kokici and colleagues (2023) found that the characteristic graded self–other pattern was present in metacognitive sensitivity but absent in metacognitive efficiency. This dissociation suggests that self-biases in episodic memory may be supported by neural mechanisms that influence memory encoding or retrieval, rather than by enhanced efficiency of metacognitive monitoring.

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A critical component of self- and other-referential episodic memory is the binding of contextual details, including information about the agent to whom a memory is attributed, a process commonly referred to as source monitoring. Source memory is often considered a more sensitive index of episodic memory quality than item memory alone, as it requires the integration of content with contextual features present at encoding (Leshikar & Duarte, 2012). Neurocognitive accounts of source monitoring implicate interactions between medial prefrontal regions involved in self- and other-referential processing and posterior parietal regions that support attentional orienting, contextual binding, and retrieval monitoring (Dobbins et al., 2002; Sestieri et al., 2017). Consistent with this framework, empirical evidence suggests that the self-reference effect extends beyond item recognition to influence source memory, indicating a qualitative enhancement of episodic representations. For example, self-referential encoding has been shown to improve both item and source recognition, consistent with more elaborative or distinctive memory traces (Durbin et al., 2017; Leshikar & Duarte, 2012; Serbun et al., 2011). However, there remains ongoing debate as to whether source memory reflects a distinct cognitive process or an extension of item memory supported by shared mechanisms (Chirtop et al., 2025; Davachi et al., 2003; Dent & Martin, 2023; Glisky et al., 1995; Guo et al., 2021; Mather, 2007; Slotnick et al., 2003). In the context of self-referential processing, resolving this issue is particularly important, as source memory may differentially depend on medial prefrontal and parietal contributions to self–other representation and episodic retrieval.

Finally, it is important to consider the role of emotional valence in the self-reference effect. Prior research has demonstrated a positivity bias in self-referential memory, whereby individuals preferentially remember positive information about themselves, but not necessarily

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about socially distant others (D'Argembeau et al., 2005). Neurocognitive accounts suggest that such valence-dependent self-biases may arise from interactions between medial prefrontal systems involved in self-evaluation and posterior parietal regions supporting attentional allocation and memory monitoring (Cabeza et al., 2008; Moran et al., 2006). More recently, Kokici and colleagues (2023) applied first- and second-order signal detection analyses to examine both memory sensitivity and metacognitive monitoring across self-, close-other, and public-figure encoding conditions. They observed a general positivity bias in recognition memory across all agents, with the magnitude of this bias graded as strongest for the self, intermediate for a close friend, and weakest for a celebrity. Importantly, although positive items were recognised with higher accuracy, they were associated with reduced metacognitive sensitivity across agents, suggesting a dissociation between memory strength and confidence calibration. In source memory, self-referential advantages were observed primarily for positive information and were driven by reduced accuracy in attributing positive traits to socially distant others. Together, these findings indicate that the influence of valence on memory and memory monitoring reflects the joint contribution of self-referential and attentional monitoring systems, and varies systematically with social closeness.

To our knowledge, no previous studies have used non-invasive brain stimulation to examine the self-reference effect under conditions of incidental encoding while simultaneously assessing source memory, metacognitive efficiency, and emotional valence. Although prior stimulation work has focused primarily on medial prefrontal contributions to intentional self-referential memory, far less is known about the causal role of posterior parietal regions, which are implicated in attentional control, source monitoring, and memory evaluation. Moreover,

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while emotional valence is known to modulate self-related memory biases, its interaction with self–other encoding and metamemory at the neural level remains largely unexplored.

Accordingly, the present study applied focal transcranial direct current stimulation to either the dorsomedial prefrontal cortex or the posterior parietal cortex during an incidental self- and other-referential encoding task involving trait judgements for the self, a close friend, and a celebrity. Subsequent recognition tests assessed both item and source memory, alongside metacognitive efficiency derived from signal detection theoretic models. By orthogonally manipulating social agent and emotional valence, this design allowed us to test the independent and shared causal contributions of medial prefrontal and parietal systems to graded self–other memory effects, memory monitoring, and valence-dependent biases.

Methods

Participants

One hundred participants were recruited via the University of Kent Research Participation Scheme and local advertisements, and received either course credit or monetary compensation for their time. Participants were randomly assigned to one of four between-subjects conditions (N = 25 per condition). All participants had normal or corrected-to-normal vision, reported no history of neurological or psychiatric conditions, and had no non-removable electrical medical devices. Ethical approval was obtained from the Psychology Ethics Committee at the University of Kent.

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Design

The study employed a 2 × 2 × 3 × 2 mixed-design analysis of variance, with two between-subjects factors (stimulation site and stimulation type) and two within-subjects factors (agent and emotional valence). An a priori power analysis conducted using G*Power (Faul et al., 2007) indicated that a sample size of 100 provided 80 percent power to detect medium-sized between-subjects effects (Cohen's f approximately 0.25 to 0.29) and small-to-medium within-subjects effects and interactions (Cohen's f approximately 0.13 to 0.14), assuming sphericity and an alpha level of .05. Effect size assumptions were selected in the small-to-medium range because previous studies investigating related phenomena differ substantially in task design, stimuli, outcome measures, and analytical approach, limiting the direct applicability of their reported effect sizes to the present study. We therefore adopted conservative effect size estimates that we considered realistic for detecting theoretically meaningful interaction effects in this mixed-factorial design.

Materials

Hardware and Software

The experimental task was programmed and presented using PsychoPy3 (Peirce et al., 2019) and administered on a standard desktop computer with a monitor, mouse, and keyboard. Questionnaires and demographic information were completed using paper-based forms.

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Measures

All participants completed a tDCS safety screening questionnaire to confirm eligibility for stimulation. Mood was assessed using the Visual Analogue Mood Scale (VAMS; Folstein & Luria, 1973) to evaluate changes in positive and negative affect following stimulation in both anodal and sham conditions. Adverse effects associated with stimulation were assessed using an adapted version of the questionnaire developed by Brunoni et al. (2011), administered to participants in all stimulation groups.

Self-Other Referential Memory Task

Episodic memory was assessed using a self–other referential paradigm in which trait adjectives were encoded with reference to the self, a close friend, or a celebrity, specifically Boris Johnson, who was the UK Prime Minister at the time of testing. During the encoding phase, participants rated each target on 20 trait adjectives using a nine-point scale ranging from very inaccurate to very accurate. Each target was paired with a unique set of adjectives selected from the normative database reported by Warriner et al. (2013) and matched across conditions for emotional valence and arousal. Stimuli were presented in a pseudorandom order, with no more than two consecutive trials from the same agent condition and the adjectives used in each condition were counterbalanced evenly throughout all participants. Following encoding, participants completed an unrelated distractor task lasting approximately five minutes.

In the retrieval phase, participants completed a surprise recognition test in which the 60 previously encoded adjectives were intermixed with 60 valence- and arousal-matched distractor adjectives. For each word, participants made an old–new recognition judgement. For items

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endorsed as previously seen, participants then indicated the agent with which the adjective had been associated during encoding. Confidence ratings were collected for both item recognition and source memory judgements, allowing computation of memory sensitivity and metacognitive efficiency.

The task was self-paced, thus participants were able to take their time when encoding or retrieving responses. All participants completed the encoding phase during active stimulation. The accuracy ratings were given as continuous scales, however, confidence ratings were collected on a scale with responses constrained to integer values (1 – 9). This format is required for estimation of meta-d' within the signal detection theoretic framework (Fleming, 2017), which operates on ordinal confidence categories rather than continuous measures. For a graphic illustration of the task, please refer to Figure 1.

Focal tDCS

The focal tDCS setup included a single-channel direct current stimulator (DC-Stimulator Plus, NeuroConn), with a central electrode (2.5cm diameter) and return electrode (inner/outer diameter of 7.5cm and 9.8cm, respectively) attached using adhesive electroconductive gel and an EEG cap. The central electrode determines stimulation polarity, in this case anodal, and the return electrode constrains electrical current to the target region, preserving spatial focality (Gbadeyan et al., 2016; Villamar et al., 2013). During anodal sessions, transcranial stimulation was delivered at 1 mA for 20 minutes, with a 5-second ramp-up and ramp-down at the beginning and end of stimulation. In the sham condition, stimulation was applied for 40 seconds, including the same ramp-up and ramp-down procedure, to mimic the initial sensation of stimulation while

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avoiding any lasting neurophysiological effects. The dmPFC was located by finding 15% of the distance from the Fz towards the Fpz, whilst the PPC was located by finding Pz. Current modelling was completed using SimNIBS version 4.1 (Thielscher et al., 2015). Parameters were selected to estimate current delivery according to EEG 10-20 guided electrode positions as stated above, with the return electrode placed equidistantly around the center electrode. Electrode and gel thickness were modelled as 2 and 1mm, respectively. Standard conductivity values as provided by SimNIBS were used. We present the theoretical cortical electrical field (magnitude E) for anodal focal-tDCS to both the dmPFC and the PPC (see Figure 2).

Procedure

Participants were first presented with information about the study and provided informed written consent for their participation. Participants completed a safety screening form, demographic questionnaire, and the VAMS. Stimulation was administered during the encoding phase of the memory task. Stimulation was started at the beginning of the encoding phase with all participants completing encoding under active stimulation. Blinding was achieved by using the "study-mode" and a set of codes administered by a researcher not actively participating in data collection. Upon completion of the task, participants completed the VAMS and adverse effects checklist. To assess blinding, participants were asked to guess whether they received sham or anodal stimulation. Finally, participants were debriefed and compensated for their time.

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Statistical Analyses

Item memory performance was analysed using a 2×2×3×2 mixed-design analysis of variance (ANOVA) with Bonferroni-corrected post hoc comparisons. The between-subjects factors were Region (dorsomedial prefrontal cortex, posterior parietal cortex) and Stimulation Type (anodal, sham), and the within-subjects factors were Agent (self, close other, celebrity) and Valence (positive, negative). The dependent variable was discrimination sensitivity (d'), a measure used in signal detection theory to quantify the ability to distinguish between signal and noise. It reflects the sensitivity of an observer, calculated as the difference between the z-scores of the hit rate and the false alarm rate, independent of response bias.

$$d' = Z(hit\ rate) - Z(false\ alarm\ rate)$$

To account for hit or false alarm rates of 0 or 1, we adjusted all values by 0.5 as recommended (Hautus, 1995).

Metacognitive performance was quantified following the signal detection theoretic framework described by Fleming (2017). Following standard procedures (Maniscalco & Lau, 2012; Fleming, 2017), trials were sorted according to stimulus class (S1 vs. S2), behavioural response (S1 vs. S2 reflecting correct v incorrect responses), and confidence level, and then collapsed into count vectors (nR_S1 and nR_S2). These vectors index the number of responses at each confidence level, ordered from high-confidence S1 responses through to high-confidence S2 responses. This confidence × stimulus × response matrix forms the input to the meta-d' model, from which metacognitive sensitivity is estimated. For each participant, metacognitive sensitivity (meta-d') and metacognitive efficiency (meta-d'/d') were computed based on confidence ratings. Any condition with a d' score less than 0.1 resulted in total removal from the metacognitive

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efficiency analyses as low d' values can distort metacognitive estimates (Fleming & Lau, 2014). This resulted in the exclusion of two and five participants in the item and source metacognitive analyses, respectively. Metacognitive efficiency was the primary index of interest and was entered as the dependent variable in separate 2×2×3×2 mixed-design ANOVAs with the same factors as above.

Source memory was analysed using an analogous approach. Source discrimination sensitivity (source d') was entered as the dependent variable in a further set of 2×2×3×2 mixed-design ANOVAs. Source-related metacognitive efficiency (meta-d'/d') was calculated from confidence ratings associated with source judgements and analysed using the same factorial structure.

To assess potential effects of stimulation on mood, composite scores for negative and positive affect were calculated at pre- and post-stimulation. Negative affect comprised ratings of afraid, confused, sad, angry, tired, and tense, whereas positive affect comprised ratings of energetic and happy. Change scores were computed by subtracting pre-stimulation from post-stimulation values and analysed using ANOVAs with Region and Stimulation Type as between-subjects factors. Adverse effects were quantified by summing responses across all items of the adverse effects questionnaire, yielding a total score for each participant, which was analysed using the same between-subjects ANOVA structure.

Blinding accuracy (correct vs. incorrect guesses) was analysed using contingency and binomial approaches. Differences in accuracy between regions were assessed using a chi-square test of independence. To characterise performance relative to chance (0.5) within each region, exact binomial tests were conducted separately for each region.

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Results

Participant Characteristics

A 2 (Stimulation condition) × 2 (Target region) between-subjects ANOVA confirmed that groups were age-matched. There were no main effects of stimulation, $F(1, 96) = 2.10$, $p = .15$, $\eta^2_p = 0.02$, or region, $F(1, 96) = 0.65$, $p = .42$, $\eta^2_p = 0.01$, and no stimulation × region interaction, $F(1, 96) = 0.03$, $p = .87$, $\eta^2_p < 0.001$. Descriptively, mean age ranged from 19.36 to 20.48 years across cells.

Sex distribution did not differ across experimental groups. Within each region, the distribution of sex across stimulation conditions was comparable (Region 1: $\chi^2(1, N = 50) = 0.94$, $p = .33$; Region 2: $\chi^2(1, N = 50) = 0.10$, $p = .75$), and collapsing across regions there was no overall association between sex and stimulation condition ($\chi^2(1, N = 100) = 0.21$, $p = .65$).

Closeness of the friend was comparable across target brain regions (dmPFC/PPC: 8.22 v 8.32), $F(1,96)=0.32$, $p=.57$, $\eta^2_p = 0.003$, stimulation condition (sham/anodal: 8.22 v 8.33), $F(1,96)= 0.32$, $p=.57$, $\eta^2_p = 0.003$. Likewise, the interaction was not significant, $F(1,96)=0.01$, $p=.91$, $\eta^2_p <0.001$.

Familiarity of the celebrity was also comparable across target brain regions (dmPFC/PPC: 6.82 v 6.70), $F(1,96)=0.08$, $p=.78$, $\eta^2_p =0.001$, stimulation condition (sham/anodal: 6.72 v 6.80), $F(1,96)=0.03$, $p=.85$, $\eta^2_p <.001$. Likewise, the interaction was not significant, $F(1,96)=0.01$, $p=.93$, $\eta^2_p <0.001$.

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Encoding and Retrieval Response Times

Analyses examining encoding and retrieval response times are reported in Supplementary 1. Participants took significantly longer to encode celebrity-related than self- or friend-related stimuli; however, encoding and retrieval response times were not affected by stimulation or stimulation region. Although encoding time predicted subsequent memory sensitivity for celebrity items, encoding times did not differ between stimulation conditions, indicating that the observed stimulation effects on memory cannot be explained by differences in encoding or retrieval response times (see Supplementary 1 and Supplementary Table 1).

Stimulation Effects on Social Episodic Memory

For main analyses, only hypotheses relevant findings will be reported in-text. For all analysis outputs please refer to Supplementary 2 (item memory) and supplementary 3 (source memory).

Item Memory

Post-hoc comparisons are Bonferroni-corrected. Means and standard deviations across all conditions are presented in Table 1.

Memory Sensitivity (d')

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Of primary interest was the predicted Agent × Stimulation Type × Region interaction, which would indicate that the effect of active versus sham stimulation differed across self-, close-other, and celebrity-referenced items depending on the stimulated brain region. This interaction was not significant, $F(2, 192) = 0.62$, $p = .540$, $\eta^2G = .001$, indicating no evidence that dmPFC or PPC stimulation differentially influenced item memory as a function of agent.

A significant main effect of Agent was observed, $F(2, 192) = 167.62$, $p < .001$, $\eta^2G = 0.21$. Memory sensitivity was highest for self-referenced items, intermediate for items encoded in relation to a close other, and lowest for items encoded in relation to a distant other. Post hoc comparisons confirmed that memory sensitivity differed significantly between all three agent conditions. Specifically, self-referenced items were remembered more accurately than items encoded in relation to a close other, $t(99) = 3.59$, $p < .001$, $d = 0.43$, and more accurately than items encoded in relation to a celebrity, $t(99) = 10.70$, $p < .001$, $d = 1.23$. In addition, items encoded in relation to a close other were remembered more accurately than those encoded in relation to a celebrity, $t(99) = 6.92$, $p < .001$, $d = 0.80$.

There was also a significant interaction between Stimulation Type and Agent, $F(2, 192) = 6.82$, $p = .001$, $\eta^2G = .01$. Follow-up analyses examining the effect of stimulation separately within each agent condition revealed no statistically significant differences between anodal and sham stimulation for self-referenced items, $t(98) = 1.81$, $p = .07$, $d = 0.36$, close-other-referenced items, $t(98) = 0.92$, $p = .36$, $d = 0.18$, or celebrity-referenced items, $t(98) = -1.20$, $p = .23$, $d = -0.24$.

When the data were examined separately by stimulation condition, the effect of Agent remained significant under both sham and anodal stimulation. Under sham stimulation, a robust agent effect was observed, $F(2, 98) = 99.26$, $p < .001$, $\eta^2G = 0.38$. Under anodal stimulation, the

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agent effect was still significant but reduced in magnitude, $F(2, 98) = 66.89$, $p < .001$, $\eta^2G = 0.14$. This pattern indicates that stimulation to either the dorsomedial prefrontal cortex or the posterior parietal cortex attenuated the self-reference effect in item memory. Inspection of the means suggests that this reduction reflected a combination of decreased memory sensitivity for self-referenced items and increased sensitivity for items encoded in relation to a celebrity. The main effect of agent and its interaction with stimulation are illustrated in Figure 3.

Taken together, these findings indicate a self-reference effect that is modulated by stimulation type, without evidence of region-specific differences. However, given the a priori interest in potential region-specific contributions of the dmPFC and PPC, follow-up analyses were conducted separately for each region.

dmPFC. There was no main effect of Stimulation Type, $F(1, 48) = 0.10$, $p = .754$, $\eta^2G < .001$. However, a significant Agent × Stimulation Type interaction was observed, $F(2, 96) = 5.63$, $p = .005$, $\eta^2G = .02$. Follow-up analyses revealed that the self-reference effect was attenuated under anodal relative to sham stimulation: the difference between self- and other-referenced conditions was reduced, reflecting lower performance for self-referenced items and relatively higher performance for celebrity-referenced items under anodal stimulation. No simple main effects of stimulation reached significance at any agent level (all ps ≥ .092).

PPC. There was no main effect of Stimulation Type, $F(1, 48) = 0.27$, $p = .604$, $\eta^2G = .003$, and no Agent × Stimulation Type interaction, $F(2, 96) = 1.72$, $p = .185$, $\eta^2G = .005$.

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Taken together, these results suggest that anodal stimulation to the dmPFC, but not the PPC, attenuated the self-reference effect, although direct comparisons between regions were not statistically supported by the omnibus interaction.

Metacognitive Efficiency (meta-d'/d')

Data from two participants were excluded due to extremely low memory sensitivity (d' < 0.10). Mauchly's test indicated violations of the sphericity assumption for several within-subjects effects (all $p < .05$). Accordingly, Greenhouse–Geisser corrections were applied to the degrees of freedom and associated p-values where appropriate. Full model outputs are reported in Supplementary 2. Below, we focus on the primary results of interest.

The Agent × Stimulation Type × Region interaction was not significant, $F(1.84, 173.02) = 0.33$, $p = .699$, $\eta^2G = .001$. This suggests that neither dmPFC nor PPC stimulation differentially affected metacognitive efficiency across self-, close-other-, and celebrity-referenced items.

A significant main effect of Agent was observed for metacognitive efficiency, $F(1.84, 173.02) = 84.27$, $p < .001$, $\eta^2G = 0.13$, indicating that metacognitive efficiency varied as a function of the encoded agent. Post hoc comparisons showed that self-referenced items were associated with greater metacognitive efficiency than items encoded in relation to a close other, $t(97) = 2.55$, $p = .01$, $d = 0.18$, and a celebrity, $t(97) = 12.30$, $p < .001$, $d = 0.87$. In addition, items encoded in relation to a close other showed greater metacognitive efficiency than those encoded in relation to a celebrity, $t(97) = 9.75$, $p < .001$, $d = 0.69$.

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There was no evidence that stimulation modulated these agent-related differences. Neither the interaction between Agent and Stimulation Type, $F(1.84, 173.02) = 0.56$, $p = .56$, $\eta^2G = 0.001$, nor the three-way interaction between Agent, Stimulation Type, and Region, $F(1.84, 173.02) = 0.33$, $p = .70$, $\eta^2G = 0.001$, reached significance.

No main effect of Valence on metacognitive efficiency was observed, $F(1, 94) = 0.53$, $p = .47$, $\eta^2G = 0.001$. However, there was a significant interaction between Agent and Valence, $F(1.89, 177.39) = 24.57$, $p < .001$, $\eta^2G = 0.03$, indicating that agent-related differences in metacognitive efficiency varied as a function of stimulus valence. Follow-up analyses revealed a substantially larger agent effect for positive words, $F(2, 194) = 100.30$, $p < .001$, $\eta^2G = 0.22$, compared with negative words, $F(1.86, 180.43) = 15.23$, $p < .001$, $\eta^2G = 0.04$.

For positive stimuli, self-referenced items showed greater metacognitive efficiency than items encoded in relation to a close other, $t(97) = 4.26$, $p < .001$, $d = 0.38$, and a distant other, $t(97) = 13.83$, $p < .001$, $d = 1.25$. Additionally, items encoded in relation to a close other showed greater metacognitive efficiency than those encoded in relation to a celebrity, $t(97) = 8.61$, $p < .001$, $d = 0.85$.For negative stimuli, self-referenced items showed greater metacognitive efficiency than items encoded in relation to a celebrity, $t(97) = 4.55$, $p < .001$, $d = 0.44$, but did not differ from items encoded in relation to a close other, $t(97) = -0.43$, $p = .67$, $d = -0.04$. Items encoded in relation to a close other showed greater metacognitive efficiency than those encoded in relation to a celebrity for negative stimuli, $t(97) = 4.98$, $p < .001$, $d = 0.48$.

No interactions involving Stimulation Type were observed for any valence-dependent effects (all p between .44 and .91). Together, these results indicate robust agent- and valence-

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dependent differences in metacognitive efficiency, with no evidence that stimulation to either region modulated these effects.

Source Memory

Post-hoc comparisons are Bonferroni-corrected. Means and standard deviations across all conditions are presented in Table 2.

Sensitivity (d')

The Agent × Stimulation Type × Region interaction was not significant, $F(2, 192) = 0.14$, $p = .872$, $\eta^2G < .001$. Therefore, there was no evidence that active stimulation to either region selectively altered source memory performance differently across agent condition.

A significant main effect of Agent was observed for source memory, $F(2, 192) = 20.23$, $p < .001$, $\eta^2G = 0.04$. Post hoc comparisons indicated that source attribution accuracy differed between items encoded in relation to the self and those encoded in relation to a celebrity, $t(197) = 5.45$, $p < .001$, $d = 0.44$, as well as between items encoded in relation to a close other and those encoded in relation to a celebrity, $t(197) = 5.56$, $p < .001$, $d = 0.45$. In contrast, source attribution accuracy did not differ between items encoded in relation to the self and those encoded in relation to a close other, $t(197) = -0.11$, $p = .91$, $d = -0.01$.

There was also a significant interaction between Agent and Valence, $F(2, 192) = 20.67$, $p < .001$, $\eta^2G = 0.04$, indicating that agent-related differences in source memory varied as a function of emotional valence. Follow-up analyses revealed a robust effect of Agent for positive words,

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$F(2, 198) = 38.63$, $p < .001$, $\eta^2G = 0.15$. For positive stimuli, source attribution accuracy was higher for self-referenced items than for celebrity-referenced items, $t(99) = 7.50$, $p < .001$, $d = 0.87$, and higher for close-other-referenced items than for celebrity-referenced items, $t(99) = 7.72$, $p < .001$, $d = 0.89$. No difference was observed between self- and close-other-referenced items, $t(99) = -0.22$, $p = .82$, $d = -0.03$. For negative stimuli, there was no significant effect of Agent, $F(2, 98) = 0.12$, $p = .887$, $\eta^2G < .001$, indicating that source attribution accuracy did not differ across agent conditions for these words.

A significant three-way interaction between Region, Stimulation Type, and Valence was observed, $F(1, 96) = 4.78$, $p = .03$, $\eta^2G = 0.01$. Follow-up analyses conducted separately for each stimulation site revealed that the interaction between Stimulation Type and Valence was not significant for stimulation targeting the dorsomedial prefrontal cortex, $F(1, 48) = 0.58$, $p = .45$, $\eta^2G = 0.002$. In contrast, a significant interaction between Stimulation Type and Valence was observed for stimulation targeting the posterior parietal cortex, $F(1, 48) = 5.00$, $p = .03$, $\eta^2G = 0.02$.

To further characterise this effect, valence-related differences in source memory were examined separately for sham and anodal stimulation of the posterior parietal cortex. Under sham stimulation, source attribution accuracy did not differ significantly between positive and negative items, $t(24) = 1.37$, $p = .18$, $d = 0.27$. Similarly, under anodal stimulation, the difference between positive and negative items did not reach statistical significance, $t(24) = -1.78$, $p = .09$, $d = -0.36$. Complementary analyses examining the effect of stimulation within each valence condition indicated no significant differences in source memory for positive items, $t(48) = 1.50$, $p = .14$, $d = 0.42$, or for negative items, $t(48) = -1.14$, $p = .26$, $d = -0.32$.

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Although individual simple effects did not reach significance, the overall interaction pattern indicates that stimulation of the posterior parietal cortex altered the relative balance of source attributions for positive and negative information, shifting from an initial bias favouring positive items towards a relative advantage for negative items (see Figure 4).

Metacognitive Efficiency (Meta d'/d')

Data from four participants were excluded due to extremely low memory sensitivity (d' < 0.10), and a further four participants were excluded due to extreme values exceeding three standard deviations from the condition mean. Mauchly's test indicated violations of the sphericity assumption for several within-subjects effects (all *ps* < .05). Accordingly, Greenhouse–Geisser corrections were applied to the degrees of freedom and associated p-values where appropriate. Full model outputs are reported in Supplementary 3. Below, we present the primary results of interest.

The Agent × Stimulation Type × Region interaction was not significant, $F(2, 176) = 1.44$, $p = .240$, $\eta^2G = .002$. This finding indicates that stimulation did not differentially influence metacognitive efficiency for source-memory across the three agent conditions.

A significant main effect of Agent was observed, $F(2, 176) = 47.42$, $p < .001$, $\eta^2G = 0.07$. Post hoc comparisons showed that memory performance differed across all agent conditions. Specifically, self-referenced items were associated with higher performance than items encoded in relation to a close other, $t(88) = 2.39$, $p = .02$, $d = 0.17$, and higher performance than items encoded in relation to a celebrity, $t(88) = 9.37$, $p < .001$, $d = 0.65$. In addition, items encoded in

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relation to a close other showed higher performance than those encoded in relation to a celebrity, $t(88) = 6.98$, $p < .001$, $d = 0.49$.

A significant main effect of Valence was also observed, $F(1, 88) = 277.97$, $p < .001$, $\eta^2G = 0.47$,with the marginal means indicating efficiency for negative items ($M = 0.95$, $SD = 0.84$) to be better than positive items ($M = 0.4$, $SD = 0.58$).

Mood change, adverse effects and blinding

Please see supplementary 4 and 5 for full details. Briefly, no stimulation dependent differences in mood change or adverse effects were identified at either region. Blinding was achieved at the PPC. Participants were better than chance at detecting the correct stimulation condition at the dmPFC.

Discussion

The present study investigated how focal tDCS to the dorsomedial prefrontal cortex (dmPFC) and posterior parietal cortex (PPC) modulates self-referential memory across three levels of social distance: self, close other, and celebrity. As expected, we observed a robust self-reference effect, with memory performance highest for self-related information and close-other judgments falling intermediately between self and celebrity. This pattern reinforces the well characterised gradient of mnemonic advantage tied to personal relevance and aligns with previous behavioural work showing graded self, close-other, and familiar-other advantages (Chirtop et al., 2025; Serbun et al., 2011). Notably, focal tDCS to either the dmPFC or the PPC

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attenuated the SRE in relation to distant others, with no effect on memory for close others. In addition, PPC stimulation was associated with a valence-dependent pattern in source memory, although this effect should be interpreted cautiously given the absence of significant follow-up comparisons.

It is important to recognise that the self, close other, and celebrity conditions differ on several dimensions beyond social distance alone. Relative to celebrities, representations of the self and close others are typically associated with richer person knowledge, greater emotional significance, and more accessible, well-established representations (Conway, 2005; Courtney & Meyer, 2020; Krienen et al., 2010). These characteristics are likely to covary with social closeness and may jointly contribute to the graded memory advantage observed here. Rather than representing alternative explanations for the present findings, these factors are likely to constitute the broader cognitive architecture through which social closeness influences episodic memory (Symons & Johnson, 1997). Consequently, our findings are best interpreted as reflecting the combined influence of these naturally co-occurring properties of socially meaningful person representations, rather than social distance in isolation.

It is important to distinguish between item and source memory, as these measures index partially dissociable components of episodic retrieval and showed different patterns in the present study. Item memory reflects recognition of previously encountered stimuli, whereas source memory requires retrieval of contextual details, such as the encoding agent. In the current findings, stimulation effects diverged across these measures. Specifically, anodal stimulation to both the dmPFC and PPC attenuated the self-reference effect in item memory, reflected in a reduced graded advantage for self-related information. In contrast, source memory did not show

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a comparable attenuation of the self-reference effect but instead exhibited a valence-dependent pattern under PPC stimulation. This dissociation highlights that item recognition and contextual binding processes may be differentially sensitive to neuromodulation and should be interpreted separately.

This pattern of stimulation effects offers important insight into how medial prefrontal and posterior parietal regions support the encoding of person information across a gradient of familiarity. It is consistent with a rebalancing of mnemonic prioritisation across social targets. Both dmPFC and PPC are implicated in controlled reflective processes, person knowledge retrieval, and attentional allocation, which are typically engaged more strongly for unfamiliar or low-relevance social targets (Ciaramelli et al., 2008, 2020; Sestieri et al., 2017; Wagner et al., 2012). Recent work has extended these accounts by showing that the neural representation of others becomes increasingly differentiated from the self representation as social distance increases, with celebrity targets showing the greatest differentiation (Courtney & Meyer, 2020). These findings suggest that neuromodulation may rebalance representational or attentional weighting across the social mnemonic gradient rather than selectively amplifying processing for distant others. In this context, the observed reduction of the self-reference effect, alongside valence-specific effects of PPC stimulation on source memory, points to a network-level modulation of control and monitoring processes rather than enhanced encoding of any single social category.

The observed pattern may reflect how the social brain differentially supports the construction and updating of person representations across levels of familiarity. The dmPFC is consistently implicated in forming trait impressions, generating mental state inferences, and

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integrating sparse social information when thinking about others who are not well known to the observer (Baetens et al., 2014; Ferrari et al., 2016). These findings converge with causal evidence from focal high-definition tDCS, which suggests that dmPFC stimulation can alter the integration of other-related information into self-representations during explicit, higher-order social cognitive tasks (Martin, Dzafic, et al., 2017). Consistent with this interpretation, neuromodulation of the dmPFC appeared to reduce the relative prioritisation of self-related information. Processing socially distant individuals is thought to require greater constructive effort and greater reliance on domain-general reflective systems than processing the self, which draws on well-established personal schemas. Modulating dmPFC activity may therefore alter the relative contribution of these processes without producing net gains in memory for unfamiliar individuals. The parallel effects observed with PPC stimulation further suggest that these operations depend on coordinated interactions between medial and parietal subsystems of the default mode network, which together support attentional control, monitoring, and the elaboration of social information during encoding and retrieval (Li et al., 2014).

These results also align closely with the self–other representational gradient described by Denny et al. (2012), who demonstrated that ventral medial PFC regions support introspective and affectively rich self-knowledge, whereas dorsomedial regions are recruited more strongly when thinking about psychologically distant others. More recent work has refined this account by showing that representational similarity in medial PFC varies continuously with subjective closeness across multiple social categories, ranging from the self to close others, acquaintances, and celebrities (Courtney & Meyer, 2020). The present findings are consistent with this organisational framework. Memory for self-related information, which draws on robust and

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highly accessible representations, remained largely unaffected by stimulation. Rather than selectively enhancing memory for socially distant targets, tDCS appeared to attenuate the relative advantage typically afforded to self-related material, thereby reducing the self-reference effect. In this context, stimulation may have altered the balance of engagement along the self–other gradient, influencing how cognitive and neural resources were distributed across social targets without producing uniform gains in memory performance.

Finally, these findings contribute to a growing literature examining whether non-invasive brain stimulation can modulate self-referential processing and related social cognitive functions. Although some studies report effects of dmPFC stimulation on self-referential encoding or metacognitive bias (Burden et al., 2021; Mattes & Soutschek, 2025), others find more limited or task-specific effects, particularly when stimuli are neutral or when processing relies on automatic rather than reflective operations (Bao et al., 2021). Our data support the view that stimulation effects are more likely to emerge when tasks engage controlled, effortful social cognitive processes, such as constructing representations of unfamiliar others, rather than when tasks rely on well established and strongly encoded self or close-other schemas. This distinction may help explain the heterogeneity in the stimulation literature and suggests that functional specificity within the social brain offers a principled framework for predicting when neuromodulation will influence social memory.

Although stimulation influenced item memory accuracy, there was no corresponding change in metacognitive efficiency, suggesting that tDCS altered the quality of mnemonic evidence without affecting the ability to monitor that evidence. Both the dorsomedial prefrontal cortex (dmPFC) and the posterior parietal cortex (PPC) are involved in memory performance

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(Berryhill, 2012; Martin, Dzafic, et al., 2017; Sestieri et al., 2017), yet neither region is believed to provide a general mechanism for metacognitive monitoring in simple item recognition tasks. The PPC contributes to attentional selection and the accumulation of evidence during retrieval, so stimulation can strengthen or weaken the memory signal used for recognition without changing how confidence reflects that signal. In a similar way, mPFC contributions to metacognition appear to be domain specific, supporting self-referential or socially inferential forms of evaluation rather than general confidence judgments for basic episodic decisions (Fleming et al., 2014; Mattes & Soutschek, 2025). When stimulation affects the strength of memory evidence but does not alter monitoring networks in anterior prefrontal, cingulate, or insular regions, accuracy can change while the relation between evidence and confidence remains stable. As a result, metacognitive efficiency is preserved even when stimulation modulates memory performance.

The present results provide tentative evidence that anodal stimulation of the PPC may modulate the balance of source memory for positive and negative information. Although the overall interaction between stimulation and valence was significant, follow-up simple effects and pairwise comparisons did not reach statistical significance. As such, the observed pattern, characterised by a relative shift away from positive and toward negative source attributions under anodal stimulation, should be interpreted cautiously.

One possible interpretation is that PPC stimulation biases attentional or contextual binding processes toward more salient or motivationally relevant information, such as negative stimuli (Klein et al., 2008). Negative words are typically processed with greater attentional weight and stronger contextual encoding (Dent & Martin, 2023; Narhi-Martinez et al., 2023), and enhancing PPC excitability may therefore amplify these processes. However, given the absence

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of significant simple effects, this account remains speculative and requires replication. Future work will be necessary to determine whether PPC stimulation reliably produces valence-dependent changes in source memory.

An alternative interpretation of the present findings is that the observed effects may reflect more general changes in attentional allocation or encoding processes, rather than modulation of self-referential processing per se. Both the dmPFC and PPC are implicated in attentional control and the allocation of cognitive resources during encoding and retrieval (Ciaramelli et al., 2008; Sestieri et al., 2017), raising the possibility that stimulation altered the distribution of attention across social targets or influenced the depth or strategy of encoding. For example, stimulation may have promoted more uniform or effortful processing across conditions, thereby reducing the relative advantage typically afforded to self-relevant information. These accounts are not necessarily mutually exclusive with a self-referential interpretation; rather, they suggest that the attenuation of the self-reference effect may arise from an interaction between self-referential mechanisms and domain-general processes such as attention and elaborative encoding. Future studies incorporating direct measures of attentional allocation or encoding strategies will be important for disentangling these possibilities.

The present findings should be interpreted in light of several limitations. The use of short-term recognition of isolated verbal stimuli may have limited sensitivity to stimulation effects, particularly given that the dmPFC is more strongly engaged during evaluative, contextual, and socially meaningful forms of memory (Amodio & Frith, 2006; Van Overwalle, 2009). Moreover, social memory differs according to characteristics of both close and distant others (Courtney & Meyer, 2020; Dent & Martin, 2023; Kokici et al., 2023; Krienen et al., 2010; Mitchell et al., 2006;

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Sumar & Martin, 2024; Symons & Johnson, 1997) and should be assessed in future studies. Although focal montages improve spatial precision, current spread beyond the targeted regions cannot be excluded, raising the possibility that effects reflect modulation of broader frontoparietal networks. In addition, tDCS effects are state-dependent and subject to substantial inter-individual variability, which may have contributed to heterogeneous effects in the absence of individualised electric field modelling or physiological measures (Niemann et al., 2024). For example, given documented cultural, sex- and gender-related differences in social cognition, emotional processing, and responsiveness to non-invasive brain stimulation, future studies should explicitly examine whether the observed effects vary accordingly (Adenzato et al., 2017; Martin et al., 2021; Martin, Huang, et al., 2017; Martin, Su, et al., 2019). Blinding was not achieved at the dmPFC, although this is unlikely to explain the pattern of stimulation results. Finally, the focus on short-term outcomes precludes conclusions about longer-term consolidation processes or underlying network-level mechanisms, which should be addressed in future work using more ecologically valid tasks and multimodal approaches.

In summary, focal stimulation of the PPC and dmPFC produced both shared and dissociable effects on episodic memory. Stimulation to either region attenuated the self-reference effect in relation to distant others. By contrast, PPC stimulation was associated with a valence-related pattern in source memory, characterised by a relative shift favouring negative over positive information, consistent with differential modulation of affective prioritisation processes. Together, these patterns suggest that focal tDCS may engage multiple, partially dissociable mechanisms, with item recognition and source memory reflecting distinct processes that differ in their sensitivity to parietal and medial prefrontal stimulation. Future work

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combining stimulation with neuroimaging or computational modelling, and extending investigation to clinical or ageing populations, will be important for determining whether these effects reflect common network-level modulation or distinct processes whose functional impact varies across social and emotional contexts.

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Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

Conflict of Interests

None to report

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Figure 1. Depiction of the self-other reference effect cognitive task.

Note. The participants were asked to input their friend's actual name at the beginning of the experiment. The current example uses 'Casey', but please note that this was individualised for each participant.

Figure 2. Focal-tDCS Current Modelling Across PPC and dmPFC Regions

Figure 3. *Item Memory Sensitivity (d') Scores across both Stimulation and Agent conditions collapsed across Stimulation Region*

Figure 4. *Source memory sensitivity (d') as a function of Stimulation condition and Valence following posterior parietal cortex (PPC) stimulation.*

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Table 1. Means and standard deviations across all tasks as per stimulation condition and region of stimulation for item memory.

Outcome	Valence	Agent	dmPFC – Sham M (sd)	dmPFC – Anodal M (sd)	PPC – Sham M (sd)	PPC – Anodal M (sd)
Sensitivity (d')	Positive	Self	2.08 (0.60)	1.87 (0.59)	2.24 (0.82)	2.06 (0.83)
		Friend	1.75 (0.46)	1.71 (0.49)	1.89 (0.64)	1.78 (0.76)
		Celeb	1.14 (0.64)	1.29 (0.47)	1.24 (0.61)	1.31 (0.67)
	Negative	Self	2.22 (0.38)	2.03 (0.63)	2.18 (0.67)	2.01 (0.59)
		Friend	1.88 (0.60)	1.73 (0.67)	1.94 (0.69)	1.83 (0.69)
		Celeb	1.36 (0.62)	1.60 (0.68)	1.25 (0.64)	1.27 (0.53)
Metacognitive	Positive	Self	0.77 (0.34)	0.77 (0.23)	0.97 (0.46)	0.83 (0.37)
efficiency		Friend	0.71 (0.24)	0.75 (0.25)	0.80 (0.42)	0.63 (0.25)
(meta-d'/d')		Celeb	0.43 (0.08)	0.45 (0.07)	0.55 (0.28)	0.45 (0.23)
	Negative	Self	0.75 (0.21)	0.76 (0.21)	0.79 (0.41)	0.61 (0.29)
		Friend	0.81 (0.41)	0.79 (0.30)	0.75 (0.29)	0.61 (0.22)
		Celeb	0.69 (0.23)	0.71 (0.21)	0.55 (0.20)	0.47 (0.10)

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Table 2. Means and standard deviations across all tasks as per stimulation condition and region of stimulation for source memory.

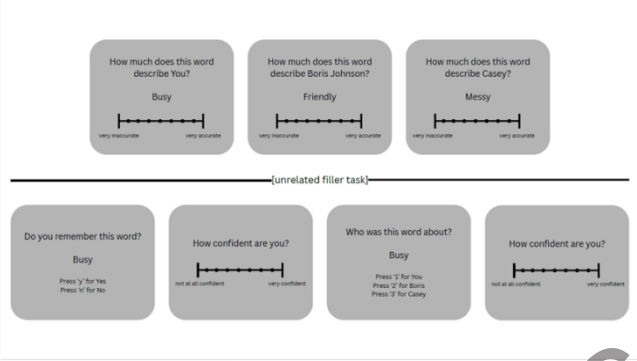
Outcome	Valence	Agent	dmPFC – Sham M (sd)	dmPFC – Anodal M (sd)	PPC – Sham M (sd)	PPC – Anodal M (sd)
Sensitivity (d')	Positive	Self	2.07 (0.51)	2.13 (0.52)	2.15 (0.63)	1.85 (0.79)
		Friend	2.05 (0.49)	2.28 (0.63)	2.12 (0.59)	1.82 (0.81)
		Celeb	1.33 (0.71)	1.63 (0.52)	1.57 (0.55)	1.49 (0.64)
	Negative	Self	1.74 (0.68)	1.82 (0.66)	1.87 (0.65)	1.89 (0.76)
		Friend	1.79 (0.66)	1.77 (0.54)	1.74 (0.60)	2.01 (0.60)
		Celeb	1.67 (0.88)	1.89 (0.70)	1.75 (0.63)	1.93 (0.48)
Metacognitive	Positive	Self	0.37 (0.04)	0.37 (0.05)	0.43 (0.12)	0.41 (0.13)
efficiency		Friend	0.37 (0.22)	0.37 (0.20)	0.32 (0.02)	0.32 (0.01)
(meta-d'/d')		Celeb	0.34 (0.06)	0.34 (0.07)	0.15 (0.01)	0.15 (0.01)
	Negative	Self	0.85 (0.32)	0.91 (0.32)	0.97 (0.30)	0.94 (0.47)
		Friend	0.92 (0.68)	0.78 (0.52)	0.91 (0.16)	0.90 (0.26)
		Celeb	0.65 (0.39)	0.66 (0.39)	0.79 (0.15)	0.75 (0.18)

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Figure 1.

Depiction of the self-other reference effect cognitive task.



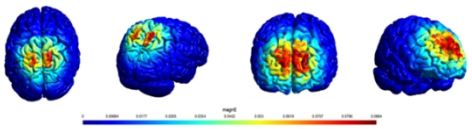
Note. The participants were asked to input their friend's actual name at the beginning of the experiment. The current example uses 'Casey', but please note that this was individualised for each participant.

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Figure 2.
Focal-tDCS Current Modelling Across PPC and dmPFC Regions



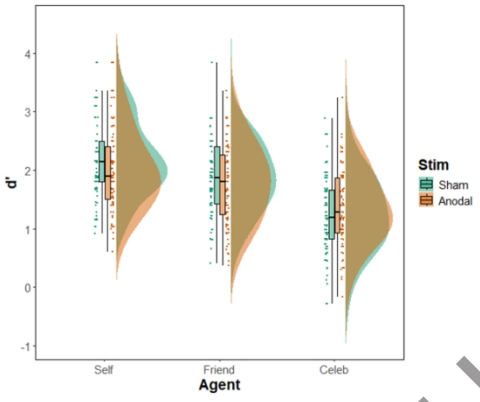
Note. Figures depict the flow and spread of electrical current when delivered at 1mA to the PPC and the dmPFC, respectively.

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Figure 3. *Item Memory Sensitivity (d') across both Stimulation and Agent conditions, collapsed across Stimulation Region*

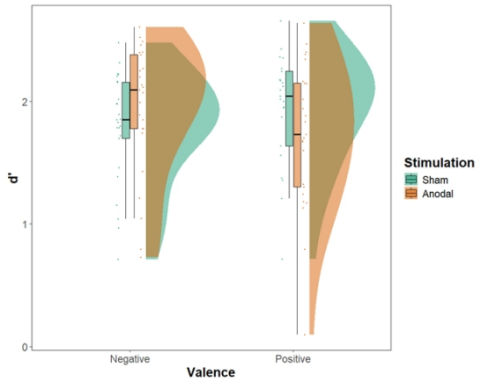


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Figure 4. Source Memory sensitivity (d') as a function of stimulation condition and valence during posterior parietal cortex (PPC) stimulation



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