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Short Communication

Transcranial direct current stimulation modulates spatial memory in cognitively intact adults

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HIGHLIGHTS

- Parietal cortex (PC) mediates categorical and coordinate spatial processing.
- We used different tDCS polarities to modulate PC functioning across three sessions.
- Coordinate spatial memory changed according to tDCS polarity.
- Anodal over left PC may enhance categorical encoding and mental imagery OR.
- Cathodal right PC may decrease neuronal competition and enhance coordinate encoding.

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ABSTRACT

Two forms of spatial processing are involved in object location memory. Coordinate processing uses a fine-grained code to provide exact knowledge for the location and is believed dependent on the right posterior parietal cortex (PPC). Categorical processing relies on spatial relationships between objects and is believed dependent on the left PPC. We used transcranial direct current stimulation (tDCS) to test these brain–behavior relationships during the encoding and subsequent recall of object location associations. Twelve right-handed, healthy young participants received 20 min of tDCS (2 mA) during three separate sessions. Stimulation delivery was counterbalanced across participants and sessions and included anodal ("excitatory") stimulation of right PPC with concurrent left PPC cathodal ("inhibitory") stimulation (R+L−), the reverse montage (R−L+), and sham stimulation. Participants completed different versions of the Object Location Touchscreen Task (OLTT) during each session, which assesses coordinate (recall of the location without the environment) and categorical processing (recall of the location with the environment). Encoding occurred during the last 5 min of stimulation, while the delay phase occurred 15 min after stimulation. Participants performed more accurately during the coordinate phase following R−L+ stimulation when compared to R+L− performance. Categorical performance was not significantly affected by stimulation. Findings suggest two possibilities that will be examined in future studies with larger sample sizes: (1) The R−L+ facilitates left-hemisphere dominant categorical processing, the benefits of which persists even when environmental details are absent, possibly due to increased mental imagery; (2) Cathodal stimulation decreased spurious neuronal noise thereby allowing for more efficient processing by the "critical" neuronal populations in the right PPC.

Remembering the location of objects is critical for everyday life.[1] Without this ability, individuals would be on a continuous search for common items such as a cellular telephones or car keys, as happens with neurologic diseases [1]. Previous research indicates that three distinct but interactive steps culminate in successful object-location memory: (1) object processing, (2) spatial-location processing, and (3) object to location binding [2–4]. These and other works have established the central role of the ventral visual stream (i.e., inferior occipitotemporal cortex) for object identification. Likewise, the hippocampal memory system is vital for object to location binding and other forms of associative memory [1,4,5]. The current report focuses on the role that different spatial processing approaches may have on subsequent memory formation.

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[1] PPC, Posterior Parietal Cortex; tDCS, transcranial direct current stimulation; R+L−, anodal stimulation over the right PPC/cathodal stimulation over the left PPC; R-L+, cathodal stimulation over the right PPC/anodal stimulation over the left PPC; OLTT, object location touchscreen task.

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Table 1
Group demographic and neuropsychological test results.

	M (SD) (*n* = *12*)
Age (years)	23.25 (4.2)
Education (years)	15.50 (2.5)
RBANS indices (standard scores)	
Immediate memory	104.58 (9.4)
Visuospatial/constructional	105.00 (12.6)
Language	102.42 (8.6)
Attention	107.08 (15.2)
Delayed memory	99.17 (4.0)
Total score	104.50 (7.9)
Line bisection (cm from center)	1.19 (2.1)
BDI-II (raw scores)	3.25 (3.7)
BAI (raw score)	2.75 (2.1)

RBANS, Repeatable Battery for the Assessment of Neuropsychological Status; BDI-II, Beck Depression Inventory, second edition; BAI, Beck Anxiety Inventory.

Postma and colleagues' [4] model posits that two spatial processing approaches exist: coordinate and categorical, which Kosslyn [6] previously postulated were mediated by the right and left posterior parietal cortex (PPC; i.e., the superior parietal lobule, intraparietal sulcus, and angular gyrus), respectively. This hemispheric distinction has been supported by functional magnetic resonance imaging (fMRI) [7,8], stroke-induced lesions [3,9,10], and non-invasive brain stimulation [11,12]. These studies focused specifically on more basic aspects of spatial processing, so it remains unclear whether memories can be biased toward one spatial processing approach or the other.

The current study used transcranial direct current stimulation (tDCS) to concurrently modulate the PPC bilaterally as participants learned and remembered object-location associations. tDCS uses weak electrical currents, delivered through scalp electrodes, to modulate underlying neuronal populations [13,14]. In the standard bipolar montage, the anode delivers the positively charged electrical current thereby depolarizing the neurons and making them more likely to discharge. Conversely, the cathode receives the negatively charged current and hyperpolarizes the neurons thereby making them less likely to discharge [14]. To our knowledge, this is the first study to examine the effects of tDCS over the PPC as it relates to memory for object-location associations. Importantly, memory was tested using two different conditions that were posited to require greater coordinate or categorical processing (see below). Given the literature reviewed above, we predicted that anodal stimulation of the right PPC (i.e., R+L−) would enhance subsequent memory test performance on the coordinate processing condition whereas anodal stimulation of the left PPC (i.e., R−L+) would enhance performance on the categorical processing condition.

A total of 18 healthy, right-handed participants, age 18–33, were screened for participation and completed a brief neuropsychological protocol [15–18] to ensure they were cognitively intact (i.e., all scores within normal limits) (see Table 1). Four of these participants were excluded after this screening session due to scores that were more than 1 standard deviation (SD) below the mean, most commonly on the Attention, Visuoconstruction, and Language Indices of the RBANS. These individuals did not undergo any additional sessions or receive tDCS. Of the 14 participants whose profiles were fully within normal limits, two were excluded during the first tDCS session. One participant was unable to undergo stimulation because of her hairstyle, which prevented accurate electrode placement (no stimulation was administered). Another participant with scalp dermatitis withdrew due to reported discomfort approximately 10 min into the stimulation session. Upon breaking the blind, however, we learned that this participant was receiving sham tDCS. Thus, 12 participants (six male) were included in the tDCS portion of the study. Demographic and neuropsychological results for these 12 participants can be seen in Table 1.

General exclusionary criteria included a history of traumatic brain injury, neurologic diseases (e.g., Parkinson's disease, dementia, epilepsy, stroke, multiple sclerosis), psychiatric illnesses (e.g., depression, anxiety, substance disorders), medication that impacts cognition (e.g., anticonvulsants, antipsychotics, anxiolytics), or any metallic or electrical implants. Prior to the start of stimulation, participants were questioned about recent alcohol use, recreational drug use, medications, and amount of sleep to rule out factors that could affect stimulation. The Institutional Review board of Emory University and the Research and Development Committee of the Atlanta VAMC approved the study procedures. All participants provided written informed consent.

The 12 participants each completed three sessions. We set an a priori requirement that sessions be separated by a minimum of 3 days in order to ensure an adequate "washout" period for any stimulation effects. Scheduling was further limited by practical issues (e.g., class/work schedules, holidays, conflicting appointments) on both the part of participants and study staff. Overall, there was an average of 7.9 days between session 1 and session 2 (SD = 3.20; range = 4–14 days) and 10.3 days between session 2 and 3 (SD = 5.79; range = 5–21 days). Thus, it is highly unlikely that any tDCS related effects persisted until the following session.

The structure of each of the three sessions was exactly the same. Each began with 20 min of tDCS (active or sham) followed by the Object Location Touchscreen Test (OLTT; see below) and ended with two additional visuospatial measures and the evaluation of ideomotor praxis, which were used to assess any non-specific effects.

Participants received two sessions of active tDCS, which was performed at 2 mA for 20 min using a NeuroConn DC-Stimulator Plus. The remaining session provided sham tDCS and consisted of a 10 s ramp up, 30 s of stimulation at 2 mA, and 10 s ramp down. Stimulation was delivered via 5 cm × 5 cm rubber electrodes that were placed within saline-soaked sponges and located at P3 and P4 based on the international 10–20 system. Two bilateral montages were used: (1) the anode was placed at P4 and the cathode was placed at P3. We refer to this as the R+L− montage; (2) The cathode was placed at P4 and the anode at P3. We refer to this as the R−L+ montage. Half of the sham sessions used each montage type.

Stimulation order was determined before the start of the study such that each stimulation condition (R+L−, R−L+, sham) occurred an equal number of times during the first, second, and third session. Likewise, participants completed one of three OLTT versions during each session, the order of which was also predetermined. These orders were placed within envelopes, sealed, shuffled, and then numbered – thereby randomizing order assignment. These procedures were used to control for potential order and practice effects across the three sessions. Envelopes were opened immediately before the first stimulation session by the lead author (H.E.), who administered the tDCS and the encoding phase of the OLTT, as well as the post-stimulation side-effects questionnaires (see Table 2). A research assistant (C.F.), who was blinded to stimulation condition, administered the memory test portion of the OLTT and the additional visuospatial measures. This distribution of labor ensured blinding to outcome (HE) and stimulation condition (CF). At no time were participants informed of the stimulation condition.

Building on our earlier work in this area [1], the OLTT was designed as an ecologically relevant memory task that would emulate the kinds of memory demands experienced in daily life. In each of three versions of the OLTT, participants learned the locations of 15 objects within five rooms that were presented on a computer screen. Memory was tested after a 15-min delay as described in detail below.

Stimuli: A total of 45 color photographs of common household objects were used in making the three test versions (15 stimuli