Modulation of Emotional Relational Memory by Neurostimulation: Evidence from a Multimodal Investigation using HD-tDCS and 7T fMRI

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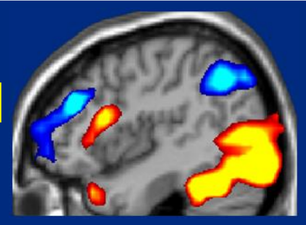
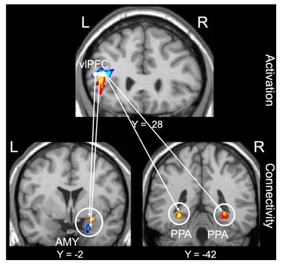


I. Introduction

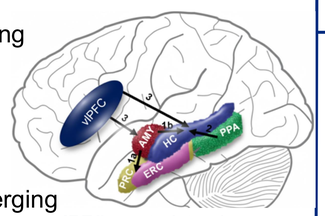
Emotion and Relational Memory:

- It is well established that emotion enhances memory for individual items, but its impact on the associated context, or relational memory (RM), remains less clear [1,2,3].
- Challenging prevalent evidence [1], recent research [4] demonstrated that emotion does not uniformly impair RM. Rather, it can enhance or disrupt it linked to attentional and contextual factors. Using a Remember/Know paradigm and an item-context matching task, this study revealed that emotional enhancement of RM occurs when conditions promote focused attention on emotion and contextual details.
- Functional MRI data identified enhanced crosstalk between the left ventrolateral prefrontal cortex (vlPFC) and the medial temporal lobe (MTL), with the former driving these interactions.



Frontal modulation of MTL activity linked to enhanced RM by emotion. Recent evidence has identified the left vlPFC) as an obvious target for neurostimulation [4]. **(Top)** White seed area indicates the overlap between clusters linked to enhanced subjective (red) and objective (blue) RM by emotion. **(Bottom)** MTL areas showing increased coupling with the vlPFC seed cluster, for subjective (red) and objective (blue) RM.

Dual Enhancement of Associative Memory by Emotion (DEAME)



- The DEAME model [5] emerging from these findings offers a comprehensive framework for understanding how emotion enhances items-context binding through two neural pathways.

vlPFC: ventrolateral Prefrontal Cortex; **AMY**: Amygdala; **HC**: Hippocampus; **PRC**: Perirhinal cortex; **ERC**: Entorhinal cortex; **PPA**: Parahippocampal Place Area

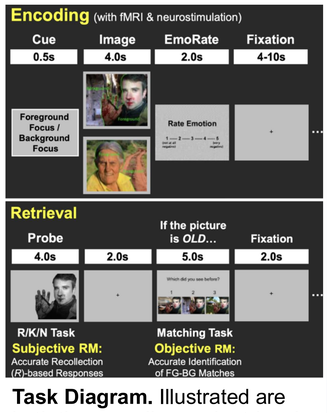
- However, directional influences within emotion-memory networks, and laminar-specific activity within vlPFC–MTL circuits, remain poorly understood. HD-tDCS allows for the causal investigation of these circuits [6,7], and the high resolution (7T) fMRI resolves laminar-level functional interactions between vlPFC and MTL structures (AMY, HC).

Aims

1. Optimize HD-tDCS montage for left vlPFC stimulation
2. Validate safety and feasibility of concurrent HD-tDCS and 7T fMRI
3. Assess HD-tDCS modulation of left vLPFC on RM performance
4. Develop a 7T acquisition and analysis pipeline for laminar-level fMRI

II. Methods

- The experiment used two sessions (2–3 days apart).
- **1. Encoding**: included 90 composite images (emotional or neutral foreground), with participants attending to either the foreground or background (neutral), followed by emotion rating [4]. HD-tDCS was applied during encoding (either sham, anodal: excitatory, or cathodal: inhibitory [9]) targeted the left vlPFC.



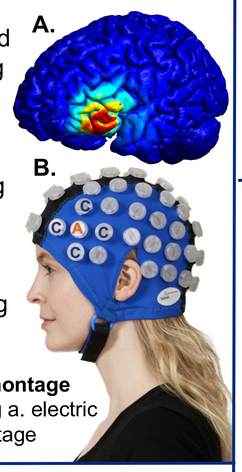
Task Diagram. Illustrated are both the encoding and retrieval phases [adapted from 4, 8].

- **2. Retrieval**: included a subjective task (Remember/Know/New) and an objective RM task (forced-choice foreground-background matching).

- Simulations were used to optimize a 4×1 electrode montage targeting **left vlPFC (MNI: −44, 28, 16)** [4]
- Safety and tolerability of the HD-tDCS protocol were assessed in 11 volunteers who completed the encoding task outside the scanner.
- **Participants** (N = 16, age: M = 18.9, SD = 0.9) were recruited from the UIUC SONA Subject Pool. The sample consisted of: 62.5% women, 31.25% men, and 6.25% agender; 43.75% Asian, 31.25% White, and 18.75% multiracial/other participants. The HD-tDCS study included three groups: anodal (N = 8), cathodal (N = 4), and sham (N = 7).

Safety tests at 3T:

- Testing at the 3T level followed a progressive approach, using a watermelon, a human cadaver head, and then a human volunteer.
- B0 field-mapping scans during 1.5 mA stimulation were acquired.
- Temperature monitoring was performed during the scanning of using the cadaver head.



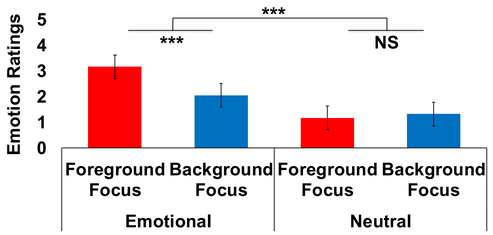
Simulation of HD-tDCS electrode montage targeting the vlPFC region, showing a. electric field magnitude and b. electrode montage

- Questionnaires revealed no side effects under sham; active stimulation produced only **mild, transient sensations**: most commonly dizziness, tingling, skin redness, and fatigue (each 18.2%), with infrequent itching or burning (9.09%).

Behavioral Task Results:

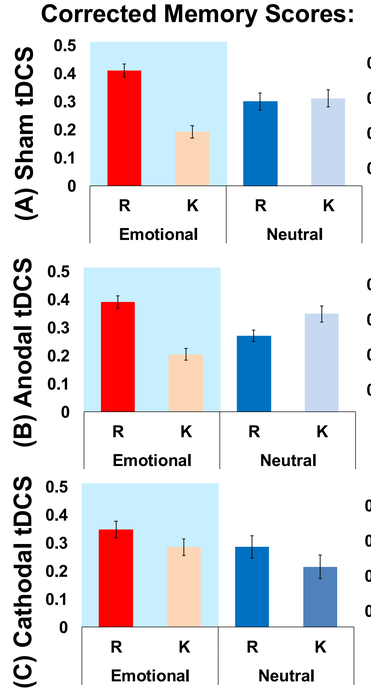
- The encoding task replicated prior findings, showing that the FA paradigm modulates subjective emotional experience [8].
- Cathodal stimulation of the left vlPFC reduced emotion-enhanced relational memory across subjective and objective RM measures, supporting the idea that vlPFC modulates the RM-enhancing effect of emotion.

Reduced Emotional Ratings for BG Focus:

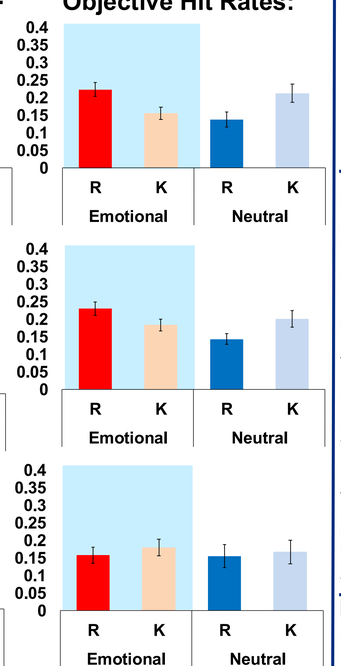


III. Results

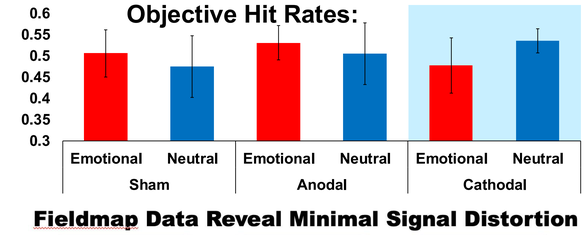
Corrected Memory Scores:



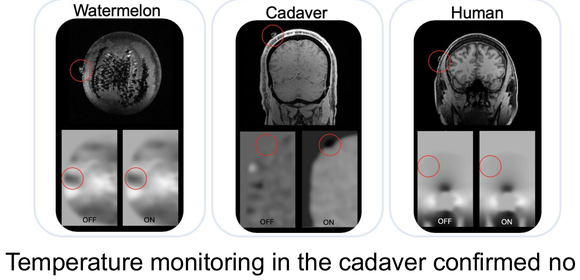
Subjective Confirmed by Objective Hit Rates:



Objective Hit Rates:



Fieldmap Data Reveal Minimal Signal Distortion



- Temperature monitoring in the cadaver confirmed no risk of electrode overheating.
- The scanned volunteer participant reported only mild and transient sensations typical of tDCS.

IV. Conclusion & Future Directions

- Concurrent HD-tDCS + fMRI is safe and tolerable for causally investigating emotional relational memory.
- As expected, stimulation did not affect emotion ratings during encoding, but modulated subsequent consolidation of emotional RM.
- Cathodal attenuation of RM provides preliminary evidence to support that left vlPFC is a necessary node for top-down emotional memory modulation.
- vlPFC stimulation selectively influences recollection over familiarity, consistent with theoretical models [4, 5].

Future directions:

- Acquire task-based 7T fMRI data during active HD-tDCS
- Increase sample sizes, vary retention intervals, and stimulation intensities.
- Validate preprocessing pipelines optimized for laminar, nuclear and subfield fMRI.

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