Examining Prefrontal Cortex Contributions to Creative Problem Solving With Noninvasive Electric Brain Stimulation

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Background & Objectives

- Cognitive neuroscience studies of creativity typically employ divergent thinking tasks that prioritize bottom-up processes to generate novel responses. However, **real-world creative problem solving** is also guided by **top-down thinking that puts an emphasis on the goal to be achieved**.
- Although the left lateral prefrontal cortex has been implicated in cognitive tasks that involve cognitive control over available information for optimal performance[1], recent research has shown that some tasks may benefit from a tradeoff between brain regions involved in rule-based processing and regions involved in object processing, particularly of object attributes or features[2-5].
- In past work[5-6] we provided evidence for such **a tradeoff between prefrontal cortex (PFC) and visual cortex** in a creative object use generation task, during which participants were asked to generate an uncommon use for a series of common objects.
- Here, we introduce the **Alternative Objects Task (AOT)**—a novel task that incorporates both bottom-up and top-down thought during problem solving. Guided by functional neuroimaging findings, we employed transcranial direct current stimulation (tDCS) over frontopolar cortex to investigate the impact of transient changes in activity in this region for problem solving performance on the AOT.
- We predicted that **inhibitory (cathodal) stimulation would facilitate performance** on generating an uncommon (but not common) object to serve a goal, whereas **excitatory (anodal) stimulation would lead to the opposite effects**. No effects of stimulation were expected for the control memory task.

Design & Methods

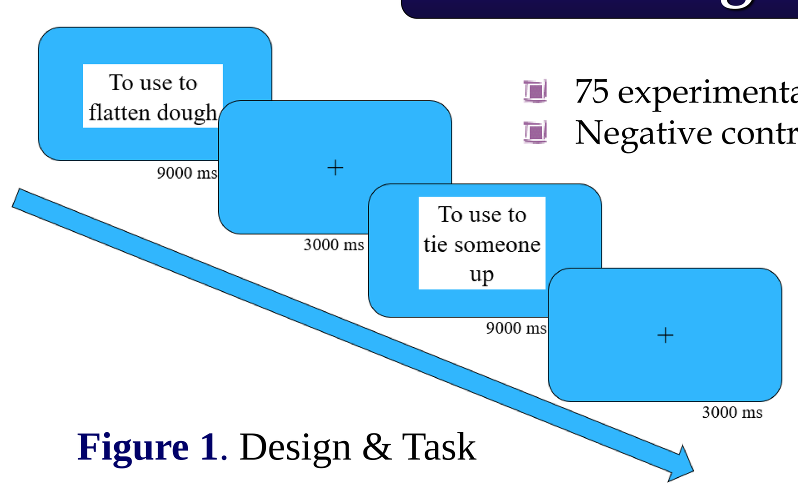

Figure 1. Design & Task

- 75 experimental trials
- Negative control FDS task

- **Dependent Measures**:
  - Number of omissions
  - Mean voice onset reaction times
  - Percent of unique responses
  - Mean latent semantic analysis scores: responses are compared to most common response in common condition
  - Subjective ratings of novelty and appropriateness

Condition	Task	tDCS Condition
Common Object Condition (n = 36)	*Generate aloud the most common object you can think of that would satisfy the goal.*	Anodal: n = 12 Cathodal: n = 12 Sham: n = 12
Uncommon Object Condition (n = 36)	*Generate aloud the most uncommon object you can think of that would satisfy the goal.*	Anodal: n = 12 Cathodal: n = 12 Sham: n = 12

tDCS Parameters

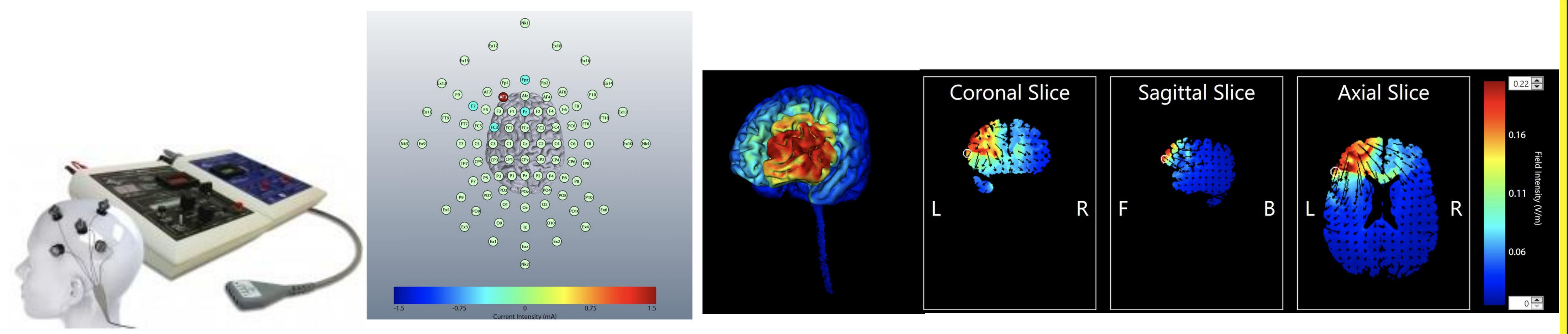

Figure 2. **HD-tDCS Montage & Prospective Electrical Field Model**

- Participants were presented with a series of goals and generated either a common or an uncommon object that could satisfy each goal, while undergoing either excitatory (anodal) or inhibitory (cathodal), or sham tDCS **over left frontopolar cortex** at 1.5mA using a HD-tDCS 4 × 1 protocol for 20 minutes.

Results

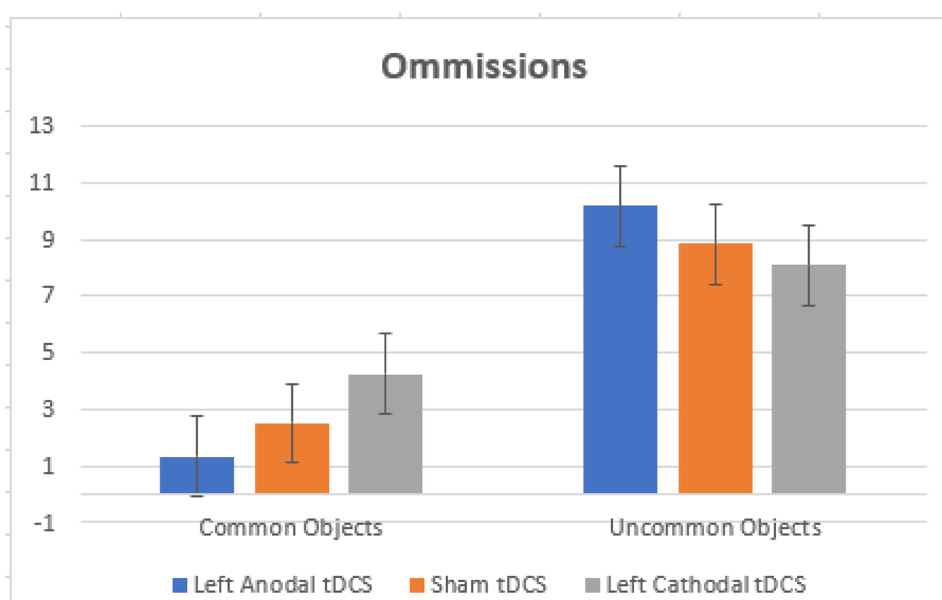

Figure 3. The task (common, uncommon object) by stimulation condition (tDCS condition) interaction was not significant for number of omissions ($F[1,72] = 1.60$, $p = .21$, $\eta^2 = 0.05$, small effect).

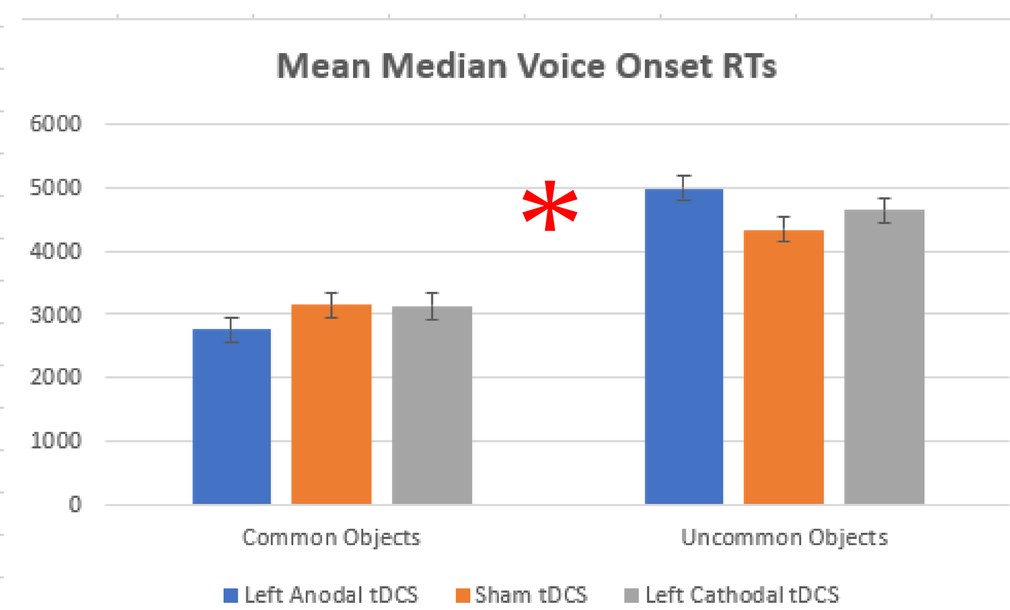

Figure 4. The task (common, uncommon object) by stimulation condition (tDCS condition) interaction was significant for voice-onset reaction times in milliseconds ($F[1,72] = 3.44$, $p = .04$, $\eta^2 = 0.09$, medium effect). Post-hoc pairwise comparisons (Tukey's HSD) did not reach significance.

Results (continued)

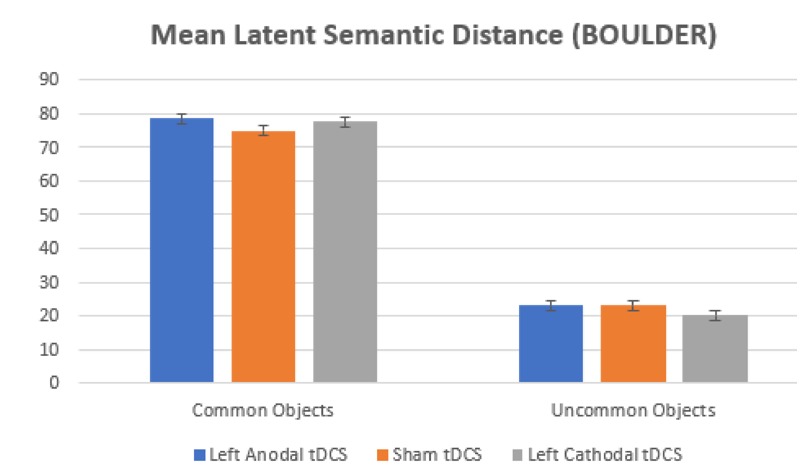

Figure 5. The task (common, uncommon object) by stimulation condition (tDCS condition) interactions were not significant for Boulder's LSA[7] ($F[1,72] = 1.89$, $p = 0.16$, $\eta^2 = 0.05$, small effect).

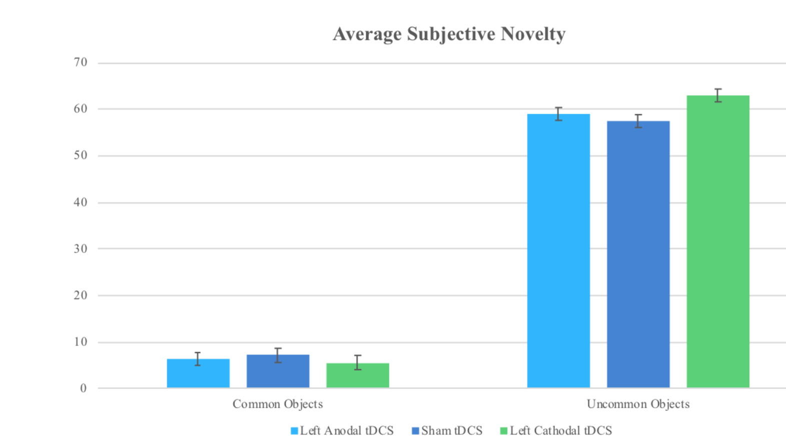

Figure 7. The task (common, uncommon object) by stimulation condition (tDCS condition) interactions were marginally significant for average subjective ratings of novelty ($F[1,72] = 3.31$, $p = 0.043$, $\eta^2 = 0.09$, medium effect).

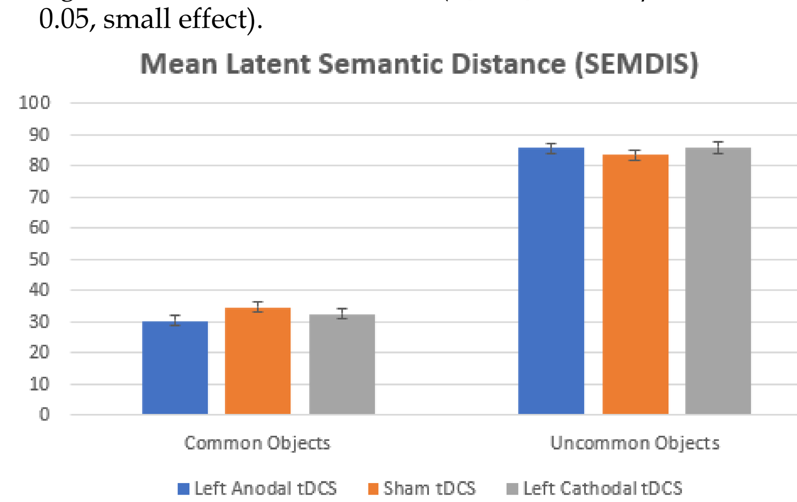

Figure 6. The task (common, uncommon object) by stimulation condition (tDCS condition) interactions were not significant for the SEMDIS LSA[8] ($F[1,72] = 2.04$, $p = 0.14$, $\eta^2 = 0.06$, small-medium effect).

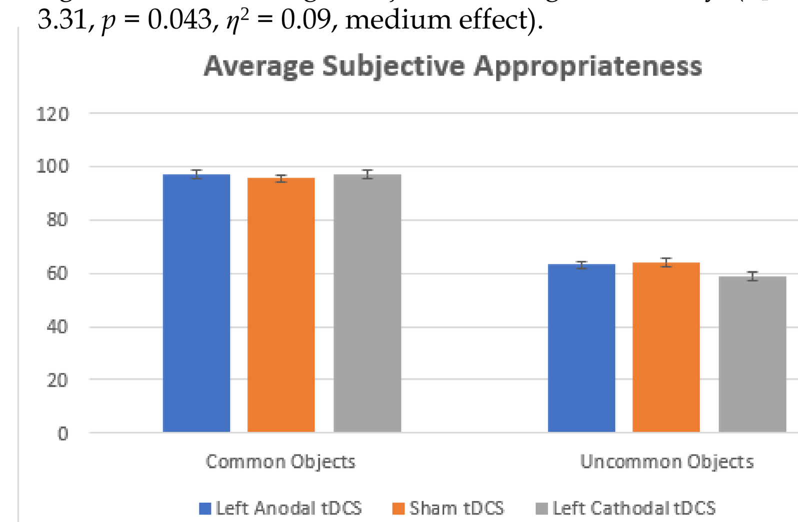

Figure 8. The task (common, uncommon object) by stimulation condition (tDCS condition) interactions were not significant for average subjective ratings of appropriateness ($F[1,72] = 2.38$, $p = 0.10$, $\eta^2 = 0.07$, small-medium effect).

FDS and Unique Percent. Stimulation had no effects on the FDS (control task) scores (percentage ($F[1,72] = 0.06$, $p = 0.94$, $\eta^2 = 0.02$) and no interaction effect for unique response percentages ($F[1,72] = 0.168$, $p = 0.85$, $\eta^2 = 0.005$).

Discussion & Future Directions

- The **significant interactions** for voice-onset RTs and subjective novelty ratings suggest that anodal over left frontopolar cortex inhibited the speed of generation of uncommon uses, whereas cathodal tDCS over the same region enhanced the novelty of the responses.
- These results **are consistent with and complement past work** using fMRI and tDCS for cognitive flexibility tasks[5-6], which have shown cathodal stimulation over left PFC to have a facilitative effect on the uncommon uses task.
- With the AOT emphasizing the goal to be achieved, anodal (but not cathodal) stimulation impeded performance on the uncommon condition (voice-onset RTs).
- A limitation of the current results is the **small sample size** per condition; data collection will continue in the near future. With increased sample size we will further determine the most common object per goal with less variability, thus, increasing the coherence of the LSA procedure.

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