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Transcranial Direct Current Stimulation Influences Reliance on Declarative vs. Procedural Learning

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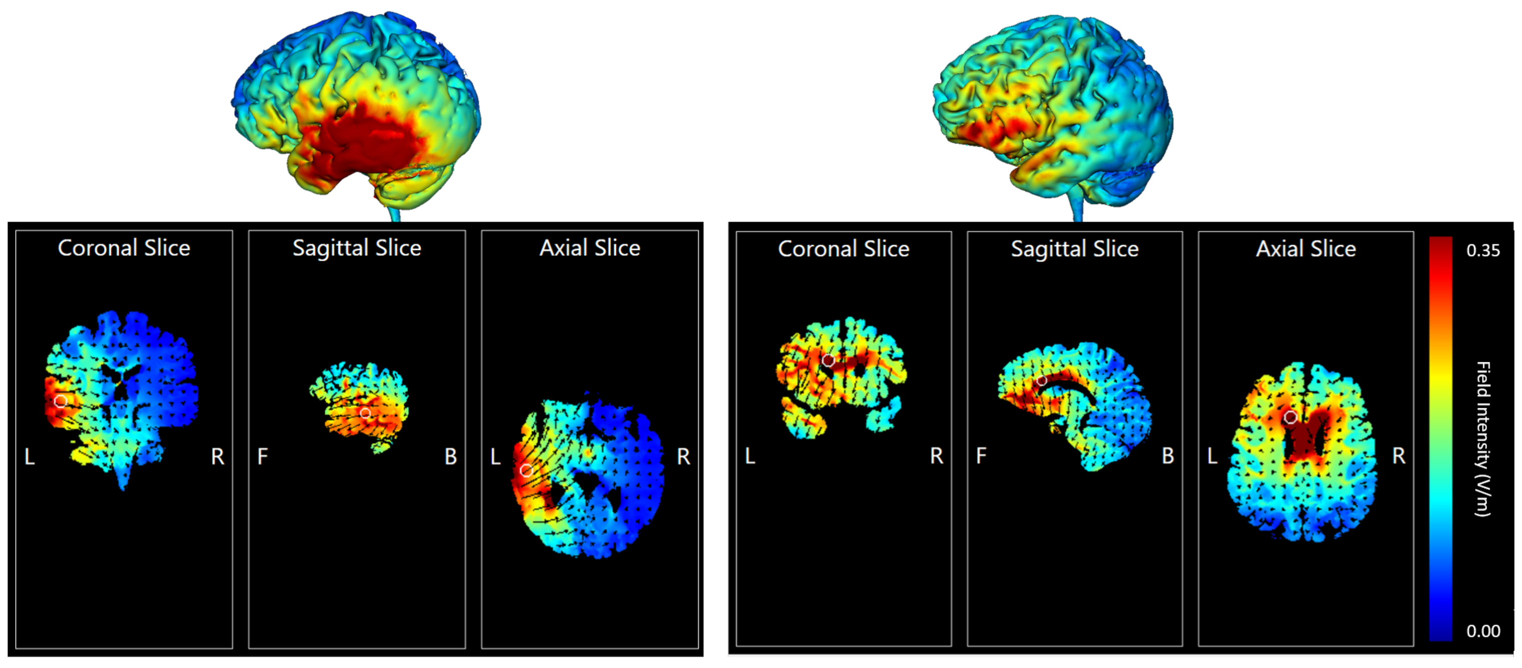
Can we use neurostimulation to shape learning pathways?

Successful language learning requires an intricate and dynamic balance between declarative and procedural mechanisms, yet individuals may rely differentially on one or the other in less than optimal ways. The goal of the current experiment was to determine whether **transcranial direct current stimulation (tDCS)** can tip the balance, specifically facilitating declarative or procedural learning. Previous research has shown that left temporal stimulation improves word retrieval in healthy adults, and that frontal stimulation augments brain activity related to reinforcement learning. We therefore predicted that anodal stimulation of the left temporal lobe would enhance an individual's reliance on declarative memory, whereas anodal stimulation of the medial/left-lateralized frontal lobe would enhance an individual's reliance on procedural learning.



Current flow model generated by Soterix HD Explore software for 1.5 mA of current. Left: temporal condition with anode electrode placement over P7 and TP7 and cathode electrode placement over EX11 (left cheek). Right: frontal condition with anode electrode placement over Fz, F1, and F2, and cathode over EX11.

BACKGROUND

- Language learning produces large individual differences in learning outcomes
  - Variation may be partially attributed to reliance on declarative vs. procedural learning pathways[1]

Declarative Learning[2]:	**Procedural Learning[2]:**
Explicit Fast (one-shot) Critical for vocabulary acquisition	Implicit Incremental, slow, error & feedback Critical for grammar acquisition

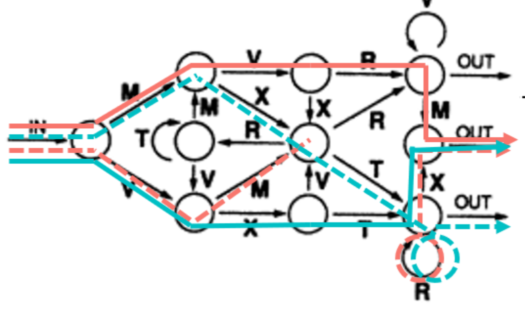
Research Question: Can tDCS targeting declarative or procedural learning pathways in the brain shift reliance on one over the other during learning?

- tDCS sends direct current from anode to cathode following path through underlying brain regions[3]

• Medial temporal lobe for general declarative learning[2] • Left temporal lobe for vocabulary[4] • Anodal tDCS over **left temporal lobe** facilitates associative verbal learning and lexical access[5]	• Dorsolateral prefrontal cortex for grammar[4] • Anodal tDCS over DLPFC facilitates artificial grammar learning[5] • Anodal tDCS over **frontal midline** enhances reinforcement learning[6]

METHODS

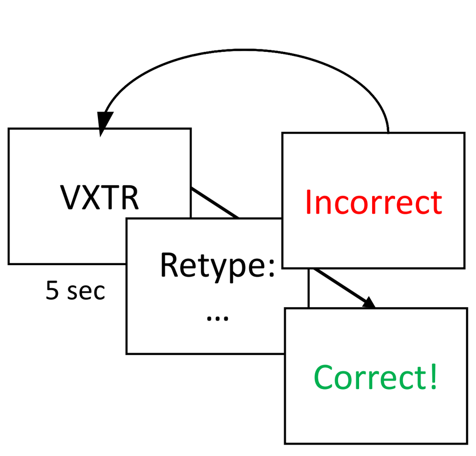
Artificial Grammar Learning (AGL) task:



2AFC Test Conditions

Measure	Example
Chunk strength isolated (grammaticality constant)	VXTX vs. MXTR
Grammaticality isolated (chunk strength constant)	MVRM vs. VMRX

Artificial grammar[6] with examples of a "correct" pathway (solid lines) and an "incorrect" pathway (dashed lines) for each condition of interest. While the incorrect grammatical pathway can be visualized easily, the incorrect (low chunk strength) pathway depends upon items presented at training



Training items used to calculate chunk strength (co-occurrence frequency of letters)					
VXTR	VXT	XTR	VX	XT	TR
MVRV	MVR	VRV	MV	VR	RV

Predictions:
Left temporal atDCS should promote explicit declarative learning, thus making it more likely for participants to choose the high chunk strength 2AFC item when grammar is held constant
Frontal atDCS should promote procedural learning, thus making it more likely for participants to choose the grammatical 2AFC item when chunk strength is held constant

SUMMARY

> tDCS facilitates access to declarative and procedural learning pathways

> Anodal tDCS over the left temporal lobe produced patterns of behavior congruent with declarative learning- fast initial learning and increased sensitivity to items at test based on similarity to training items

> Anodal tDCS over the frontal midline produced patterns of behavior congruent with procedural learning- initially slow learning that catches up quickly, and increased sensitivity to items at test based on underlying grammatical rules

atDCS Stimulation Procedures and Parameters
Two 3x5 cm sponges soaked in saline solution secured to head using head straps, 20 minutes on-line with 1.5 mA

Left Temporal Stimulation (n = 17):
- Anode placed horizontally at ~P7 & TP7 (10% of distance from nasion to inion from the inion up the midline, then 10% of the circumference from electrode Oz to the left to electrode P7/TP7)
- Cathode placed vertically between cheekbone and jawline on left cheek

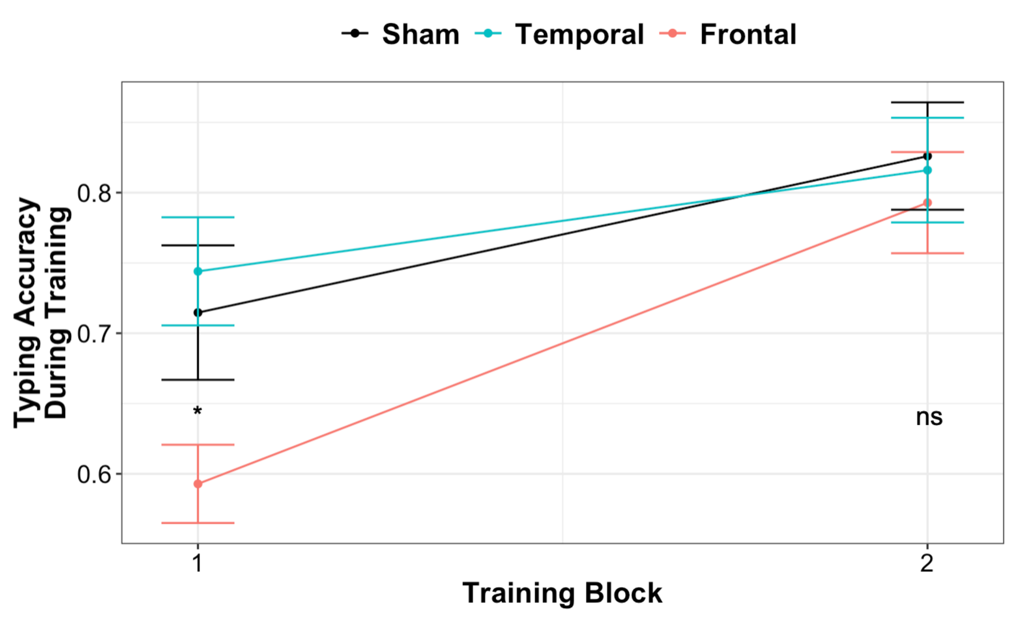
Frontal Stimulation (n = 16):
- Anode placed horizontally at ~Fz (30% of the distance from the nasion to inion from the nasion up the midline)
- Cathode placed vertically between cheekbone and jawline on left cheek

Sham Stimulation (n = 16):
- "Anode" placed in mirrored right-hemisphere location as left temporal stimulation (~P8/TP8)
- "Cathode" placed on right supraorbital area

No Stimulation Control Group (n = 31): recruited from Psychology subject pool under guise of learning and memory study

RESULTS

Training

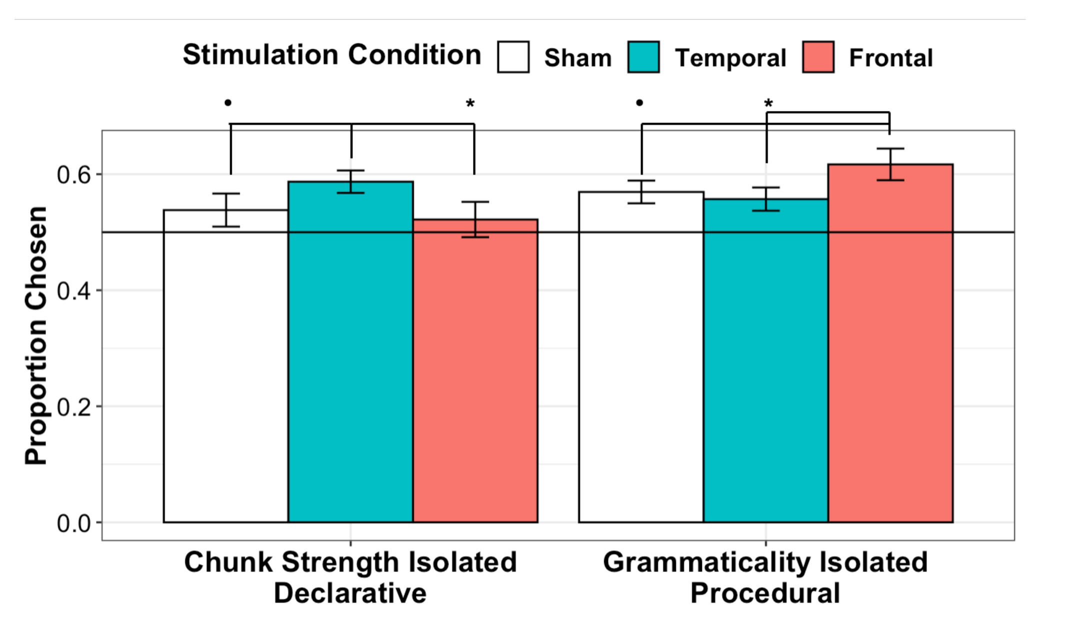


ANOVA Block * Stimulation: $F(3, 69) = 3.16$, $p = .03$
Block 1: temporal > frontal; $t(27) = 3.15$, corrected $p = .03$
Block 2: no differences (all ps > .8)

Left temporal stimulation produced fast, immediate learning

Frontal stimulation produced incremental, slow learning from error and feedback

2AFC Test



ANOVA: 2AFC Condition * Stimulation: $F(2, 46) = 2.97$, $p = .06$

Follow-up a priori t-tests::
Temporal > frontal for discriminating similarity: $t(31) = 1.83$, $p = .04$
Frontal > temporal for discriminating grammaticality: $t(31) = 1.78$, $p = .04$

CONCLUSIONS & DISCUSSION

Pattens of learning were congruent with declarative and procedural pathways, suggesting tDCS was effective in shifting how people learned

Future directions:
Generalize to natural language learning

Introduce declarative and procedural learning at different critical points in time

Characterize the effect of stimulation on brain activity, and how changes in brain activity from stimulation are related to gains in learning

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