Learning Preferences as an Index of Individual Differences in Cognitive Flexibility

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1. Introduction

- **Cognitive Flexibility (CF)** is the ability to **adapt responses** to meet unexpected environmental changes or task demands.
- Recent findings suggest that when solving problems involving cognitive flexibility, individuals who approach a learning task using exploration, outperform those who approach the task using exploitation.
- **Exploitation:** behavior characterized by choosing the option one has learned will give a specific outcome.
- **Exploration:** behavior characterized by choosing different options to examine if one is more fruitful than a previously tested option[1].
- The relationship between **cognitive flexibility** and **learning strategies** would suggest that learning preferences may capture **individual differences in cognitive flexibility**.
- This relationship might reveal possible cognitive and neural mechanisms that **support flexible thinking**[2].

2. Objectives

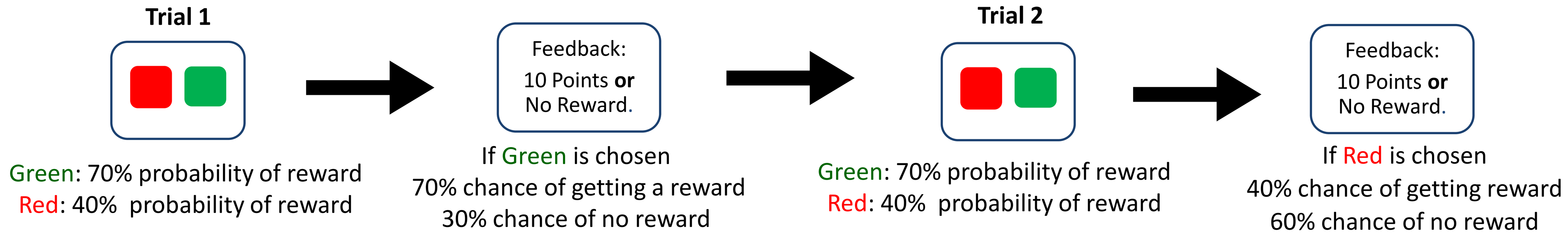
- The goal of the behavioral experiment was to examine whether individual differences in learning preferences can account for variability in cognitive flexibility performance.
- As CF has been linked to prefrontal cortex (PFC) activation, in a second study we used a similar paradigm to examine whether modulation of PFC with noninvasive brain stimulation (tDCS) would produce measurable effects on CF that would be mitigated by individual learning preferences.

Experiment 1: Behavioral Study

Subjects:	*N* = 60 (36 female) college & graduate age.
Learning Task:	Participant's response choice during task. ⬇ Binary Classification Model → Exploration / Exploitation
Cognitive Flexibility Tasks:	Task performance compared between exploration and exploitation groups.

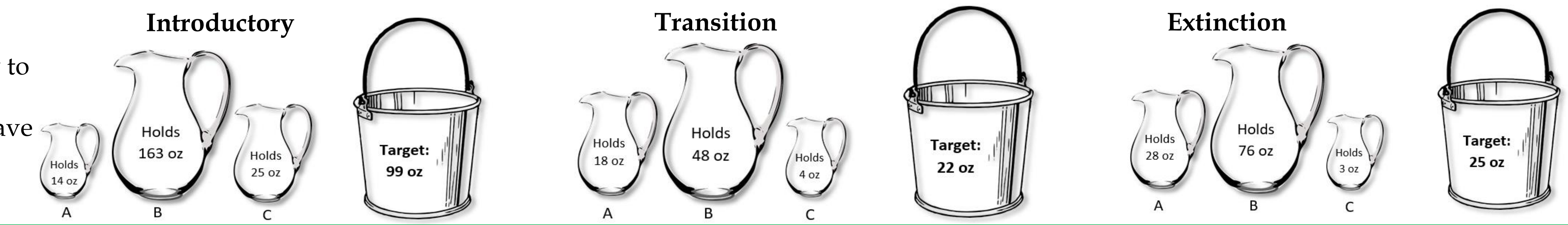
Reward-based binary choice learning task

- Participants' behavior can be biased toward **either exploitation** or **exploration**.
- **Exploitation**: Repeatedly choosing the same color option, often despite negative feedback.
- **Exploration**: Frequently switching between color option, switching regardless of positive feedback.



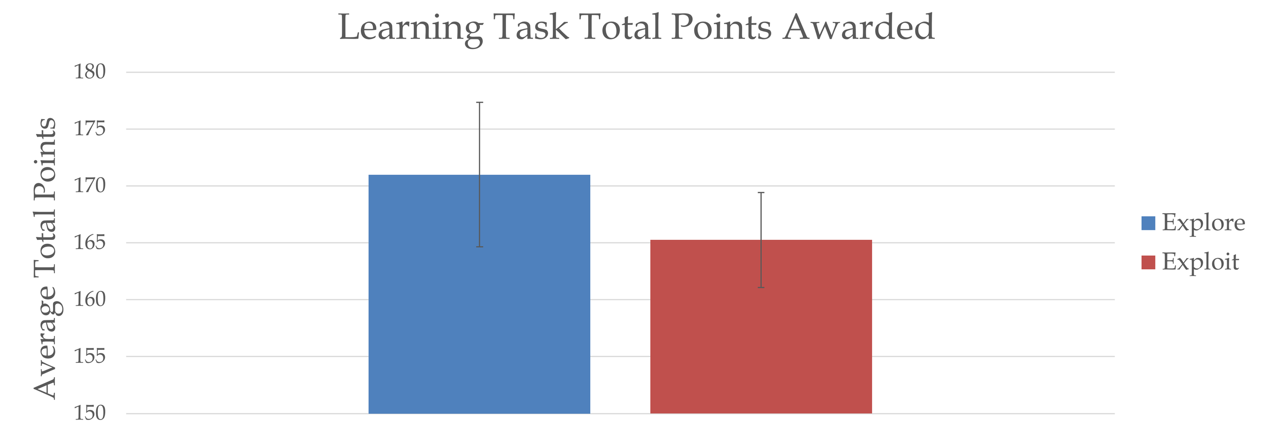
Water Jar Task [3]

- The **Einstellung effect** → the tendency to get **stuck** using a **"tried-and-true"** method when solving problems that have an efficient alternative method.



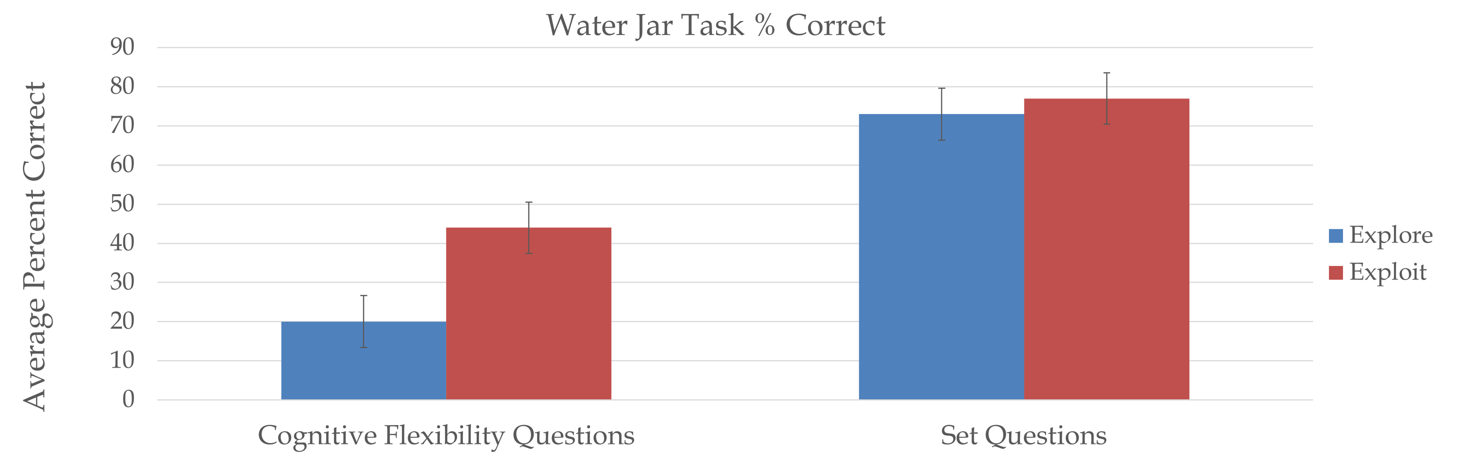
Learning Task Results

- Participants were classified with a preference toward **Exploration** or **Exploitation**, based on their performance on the learning task (choice probability of explore vs. exploit); 20 were identified as following an Explore strategy and 40 an Exploit strategy.



Water Jar Task Results

- Exploit participants outperformed Explore participants on insight problems on this task ($t[58] = -2.31$, $p = 0.024$, $d = 0.30$).



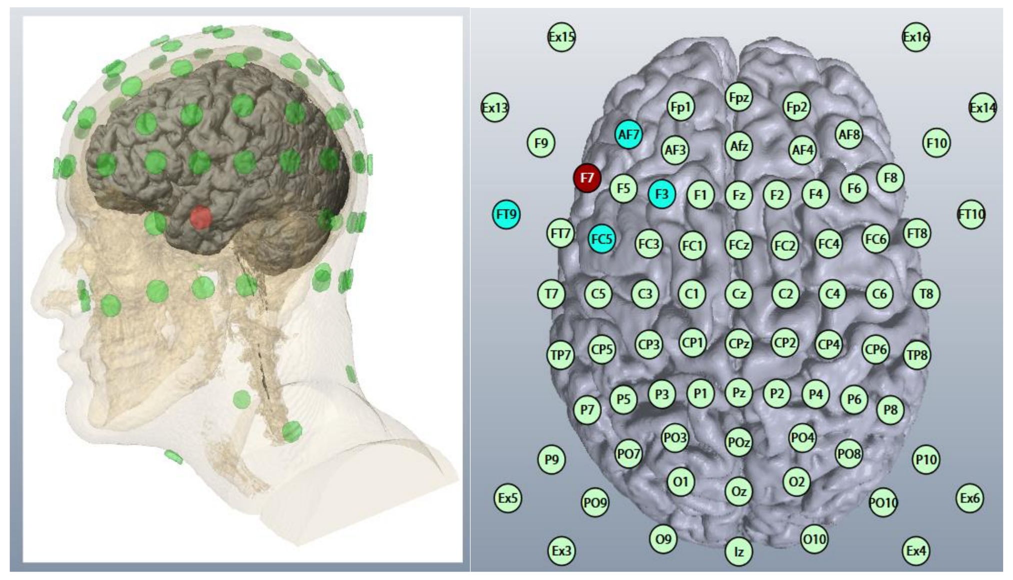
Experiment 2: tDCS Study

transcranial Direct Current Stimulation (tDCS)

- Participants were administered **Water Jar Task** and **Forward Digit Span** during stimulation.
- **1.5mA** of stimulation - electrodes in a **4x1 montage** - central electrode at **F7**.
- Participants received either **excitatory**, **inhibitory**, or **sham stimulation**.

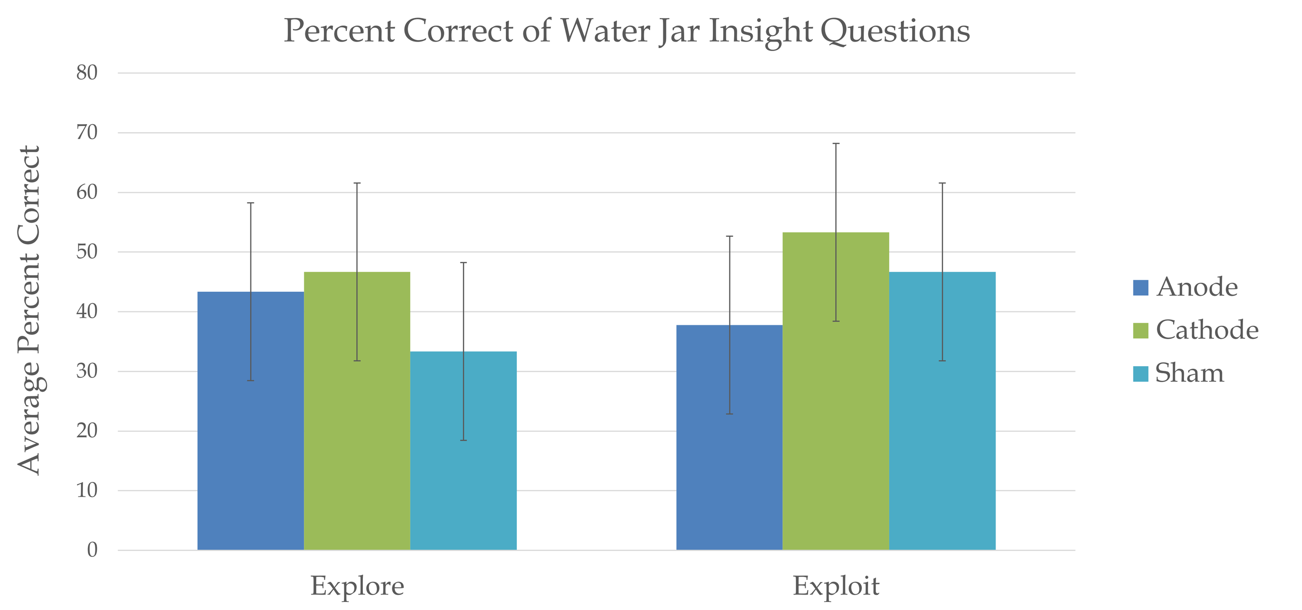
Subjects:	*N* = 45 (28 female) mean age = 20.6 years (± 5.86)
tDCS Condition:	Anodal: *N* = 15 Cathodal: *N* = 15 Sham: *N* = 15
Learning Group:	Exploit: *N* = 24 Explore: *N* = 21

Mixed Groups:	Exploit	Explore
Anode:	9	6
Cathode:	9	6
Shame:	6	9

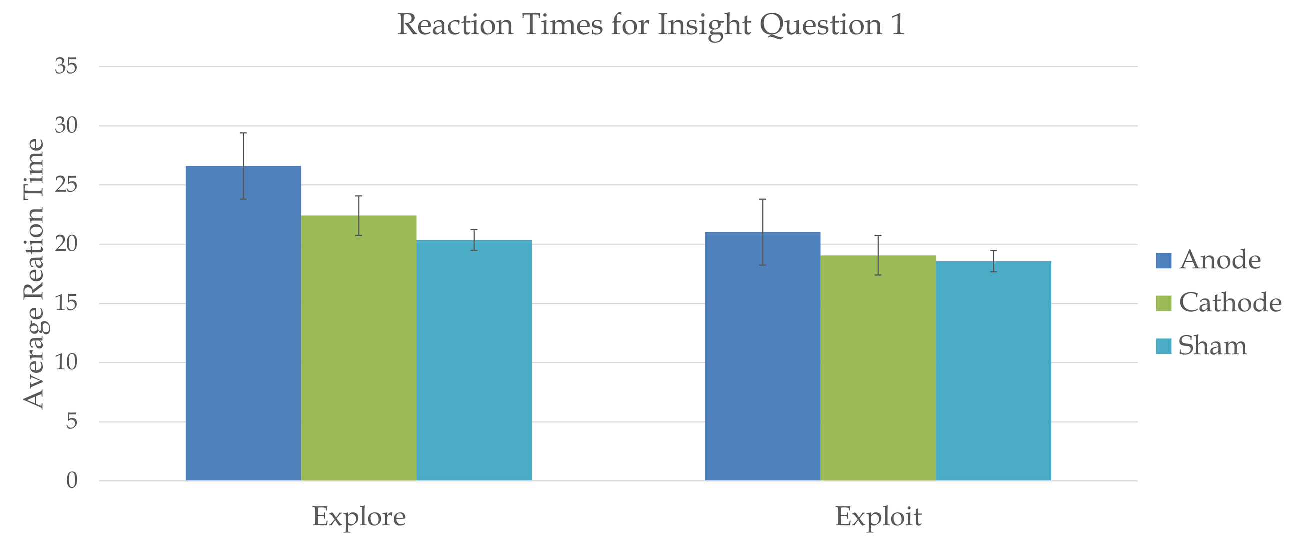


Task Results

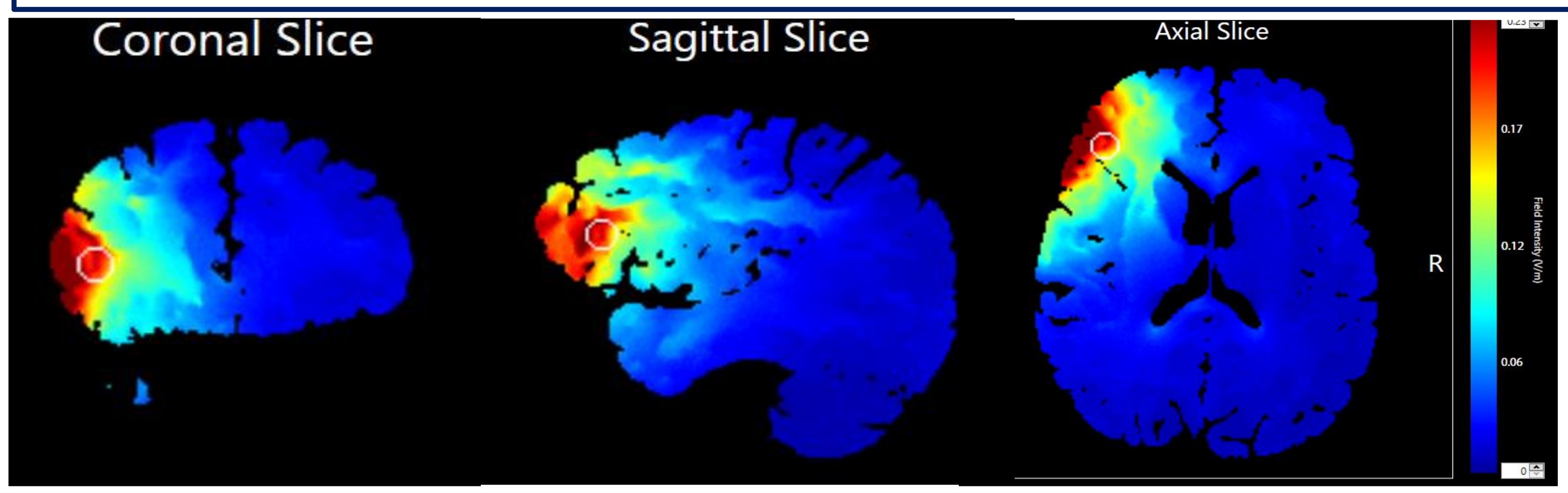
- A 2x3 mixed ANOVA assessed the effect of tDCS condition and learning group on **Water Jar task performance** (% correct on transition and extinction questions).
  - **tDCS condition:** $F(2,39) = 0.27$, $p = 0.76$, $\eta p^2 = 0.01$
  - **Learning group:** $F(1,39) = 0.15$, $p = 0.70$, $\eta p^2 = 0.004$
  - **Interaction effect:** $F(2,39) = 0.20$, $p = 0.821$, $\eta p^2 = 0.01$



- A 2x3 mixed ANOVA assessed the effect of tDCS condition and learning group on **participants' RT of transition question 1**. Seen here is the largest effect of each main effect on the time taken to complete the **first cognitive flexibility problem**.
  - **tDCS condition:** $F(2,39) = 5.49$, $p = 0.15$, $\boldsymbol{\eta p^2 = 0.85}$
  - **Learning group:** $F(1,39) = 10.50$, $\boldsymbol{p = 0.08}$, $\boldsymbol{\eta p^2 = 0.84}$
  - **Interaction effect:** $F(2,39) = 0.13$, $p = 0.88$, $\eta p^2 = 0.006$



- A **logistic regression** was performed to ascertain the effects of the interaction between learning group and tDCS condition on the likelihood that participants would solve each WJ insight problem. The logistic regression model was marginally statistically significant, $\chi^2(2) = 4.61$, $p = .10$. The model explained 17.0% (Nagelkerke R^2) of the variance in WJ Insight problem 1 correct responses and correctly classified 84.4% of cases.



5. Conclusions

- Overall, we presented two studies that attempted to explore the relationship between learning preferences and cognitive flexibility performance.
- Our results, although preliminary, suggest that participants who differ with respect to their tendencies to follow Exploit vs. Explore learning strategies perform differently on cognitive flexibility tasks. Altering activity over prefrontal cortex with noninvasive brain stimulation might be able to modulate these effects.
- By understanding how learning contributes to executive regulation and flexibility we can pave the way to conceptualize flexibility deficits as impairments of learning, and to begin formulating new approaches to their treatments.

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