Neural Correlates of Motivational States That Bias Reinforcement Learning & Memory Formation

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Background

Motivational states influence choices, actions, and memory formation [1-3]

Imperative Motivation

"Urgent Mode"

- Address **urgent threats or goals**, like avoiding danger or winning a competition
- **Narrow** focus for attention and memory
- Amygdala-MTL systems and **noradrenergic** modulation

Interrogative Motivation

"Explore Mode"

- **Explore and learn** to find rewards and prepare for future goals
- **Broad** focus for attention and memory
- VTA-hippocampal systems and **dopaminergic** modulation

How do **motivational states** influence **reinforcement learning** & **memory formation**?

Methods

Varied **cover stories** before a reinforcement learning task:

Imperative Group
(Behav n = 30, fMRI n = 27)

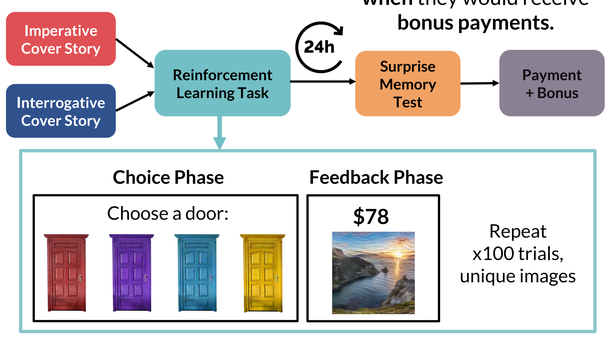
"Imagine that you are a master thief **executing a heist** at an art museum. […] **Steal** as much valuable art as you can, **before you run out of time**!"

Interrogative Group
(Behav n = 31, fMRI n = 29)

"Imagine that you are a master thief **planning a heist** and scouting an art museum. […] **Discover** valuable paintings for your **future heist**!"

fMRI Scan (w/ heart rate, SCR)

Participants had the same expectations about **how** and **when** they would receive **bonus payments.**

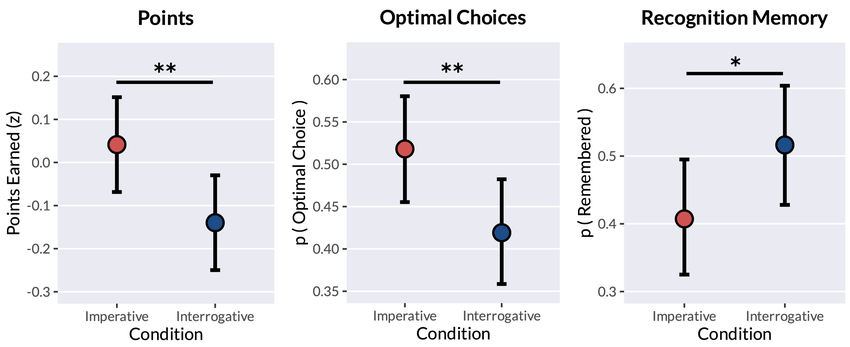


Used **computational modeling** to examine reinforcement learning (delta learning rule + softmax choice rule)

Compared **choice behavior**, **next-day memory**, and **neural activation** across the Imperative and Interrogative groups

Task Performance

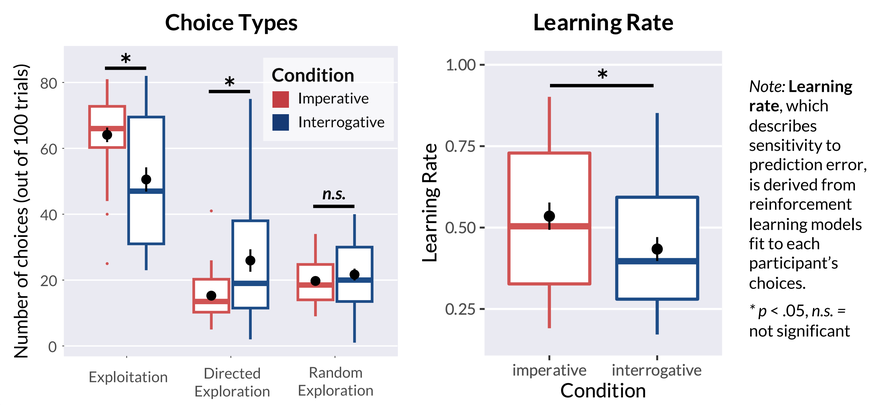
Imperative group earned more **points** and made more **optimal choices.**
Interrogative group had better **memory** for the **paintings** the next day.



Note: Plots depict estimates from mixed-effects models predicting trial-wise performance after controlling for covariates (e.g., reward schedule, learning trial). * $p < .05$, ** $p < .01$

Reinforcement Learning

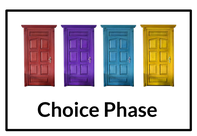
Imperative group made more **exploitative** choices (maximizing reward), whereas Interrogative group engaged in more **directed exploration** (resolving uncertainty).



Note: **Learning rate**, which describes sensitivity to prediction error, is derived from reinforcement learning models fit to each participant's choices.

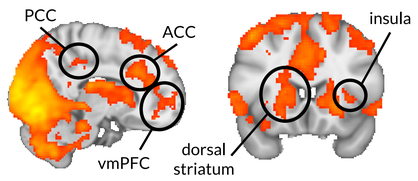
* $p < .05$, *n.s.* = not significant

Choice Phase Activation



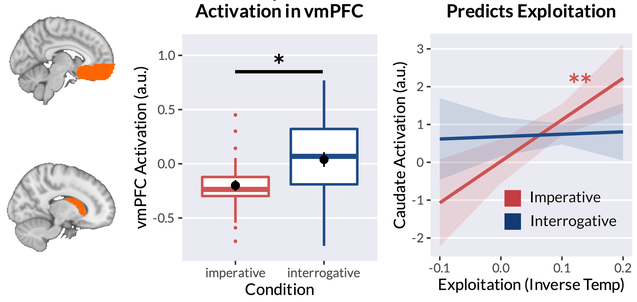
Choice > Baseline, group average (x = 12, y = 18)

z = 3.1 — z = 10.8



Interrogative group showed stronger representations of uncertainty in **vmPFC** [3].

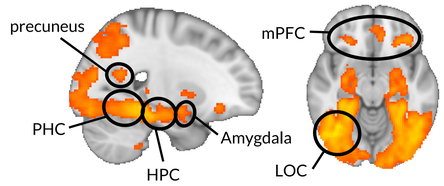
Dorsal striatal activation predicted exploitation in the **Imperative** group.



Feedback Phase Activation

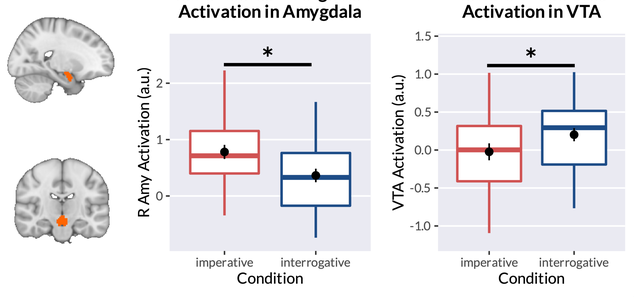
Remembered > Forgotten, group average (x = 24, z = -12)

z = 3.1 — z = 8.3



Amygdala activation predicted subsequent memory in the **Imperative** group.

Interrogative group showed stronger representations of reward in **VTA.**



Discussion

- Replicating our prior findings [1], **Imperative** motivation enhanced **short-term reward learning**, whereas **Interrogative** motivation enhanced next-day **memory**
- Motivational states shift **exploration** and **exploitation**, via neural systems for decision making and representing uncertainty (vmPFC, dorsal striatum) [4]
- Motivational states pave different routes to memory formation— **amygdala** activation predicted **memory** in the **Imperative** group, whereas **VTA** activation during encoding was modulated by **reward** in the **Interrogative** group [2,3]

Key Idea

Motivational states shift the balance between neural systems for **immediate choices** and **long-term memory** formation.

1. Sinclair*, Wang*, & Adcock (2023), *PNAS*
2. Chiew & Adcock (2019), *Cambridge Handbook of Motivation & Learning*
3. Murty & Adcock (2017), *The Hippocampus from Cells to Systems*
4. Trudel et al., (2021), *Nature Human Behavior*

Related Paper