Hippocampal contributions to the acquisition of response contingencies during value-based reinforcement learning: Lesion and neuroimaging evidence

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INTRODUCTION

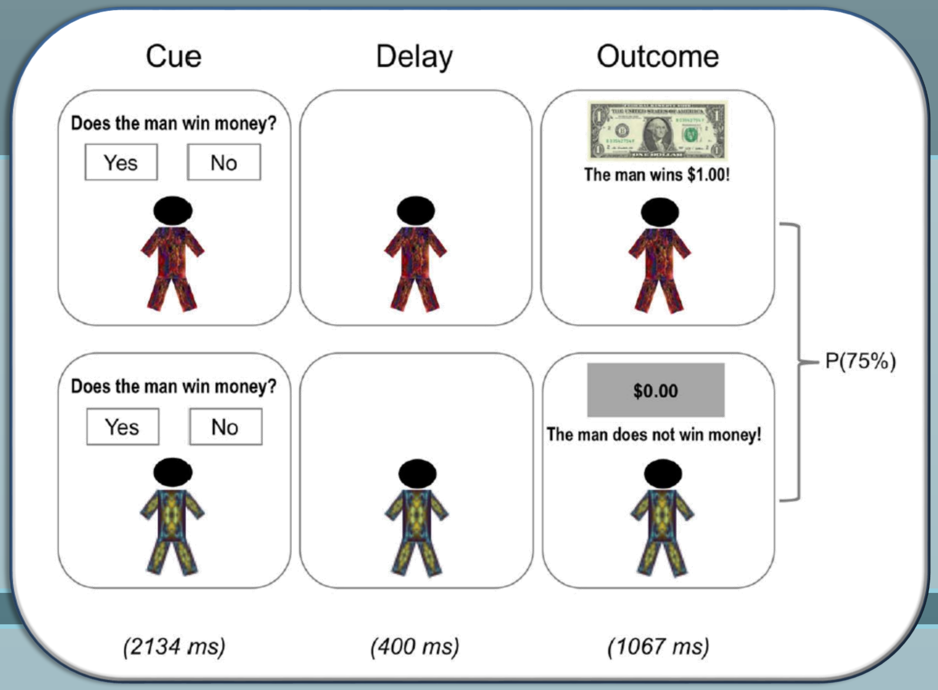
- Value-based reinforcement learning is typically associated with the basal ganglia and ventromedial PFC.
- Some studies, both in humans and non-human research, have suggested hippocampal engagement. E.g., Palombo et al. (2019) reported hippocampal involvement in a value-based probabilistic learning task.

GOAL OF THIS STUDY: Use computational modeling to elucidate the nature of hippocampal contribution to value-based reinforcement learning by reanalyzing the Palombo et al. amnesic performance & fMRI data.

METHOD

TASK

Probabilistic learning task involving learning the value of 6 visual patterns

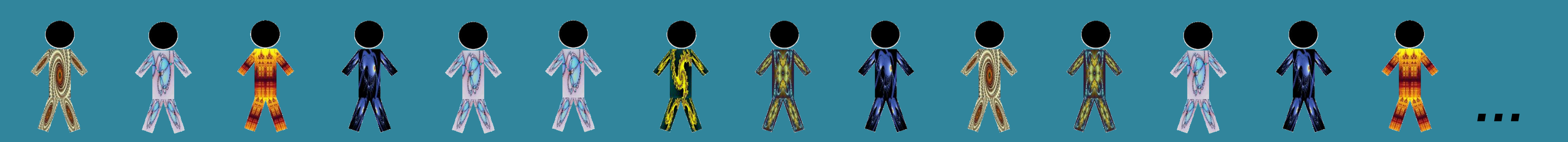


COMPUTATIONAL MODELING

MODEL 1: Classic Reinforcement Learning

Modeling mental representations of state-action values: $V(s_t, a_t)$

States (s_t): which stimulus is presented at time t



Actions (a_t): response of the participant (Y/N) at time t

Y N Y Y Y Y N Y N Y N N Y Y …

Values of "visited" states are updated based on reinforcement

$$V(s_0, a_0) = 0.5$$
$$V(s_{t+1}, a_{t+1}) = V(s_t, a_t) + \alpha\,[r_{t+1} - V(s_t, a_t)]$$

α: Updating Parameter; r_{t+1}: Reinforcement at time "t" correct=1/incorrect=0

PARAMETRIC MODULATOR
Prediction Error (PE)
$$PE_{t+1} = r_{t+1} - V(s_t, a_t)$$

MODEL 2: Classic Reinforcement Learning + Decay

Values of "non-visited" states are updated with decay

$$V(s_{t+1}, a_{Y/N}) = V(s_t, a_{Y/N}) + \textbf{decay}\,[V(s_0, a_0) - V(s_t, a_{Y/N})]$$

PARAMETRIC MODULATOR
Progressively Acquired Knowledge
$$AK_t = \sum_{\substack{states\\actions}} |V(s_0, a_0) - V(s_t, a_t)|$$

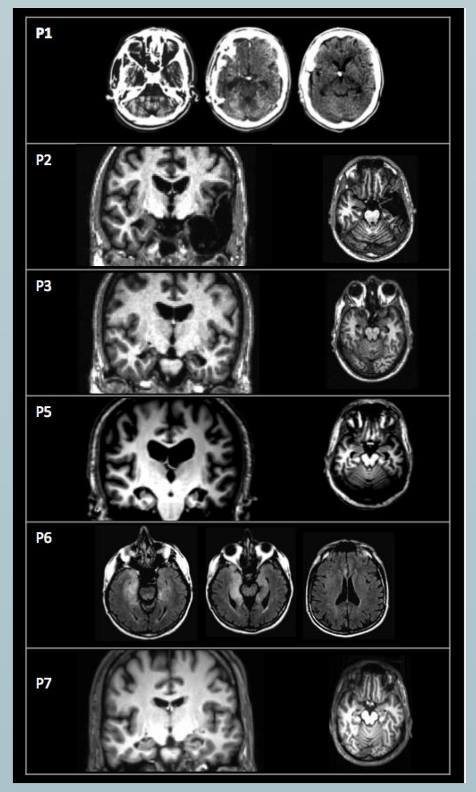
Probability of Response: Calculated from the state-action values using a logistic function (Softmax)

$$Prob(a_t = Yes/s_t) = \frac{e^{\beta V(s_t, a_t = Yes)}}{e^{\beta V(s_t, a_t = Yes)} + e^{\beta V(s_t, a_t = No)}}$$

β = exploit vs. explore response tendency
0 → random response
+∞ → systematic choice of higher value

Model Fit: Bayesian / Markov Chain Monte Carlo random walk

LESION STUDY



PARTICIPANTS

Patients with MTL lesions (N=8)

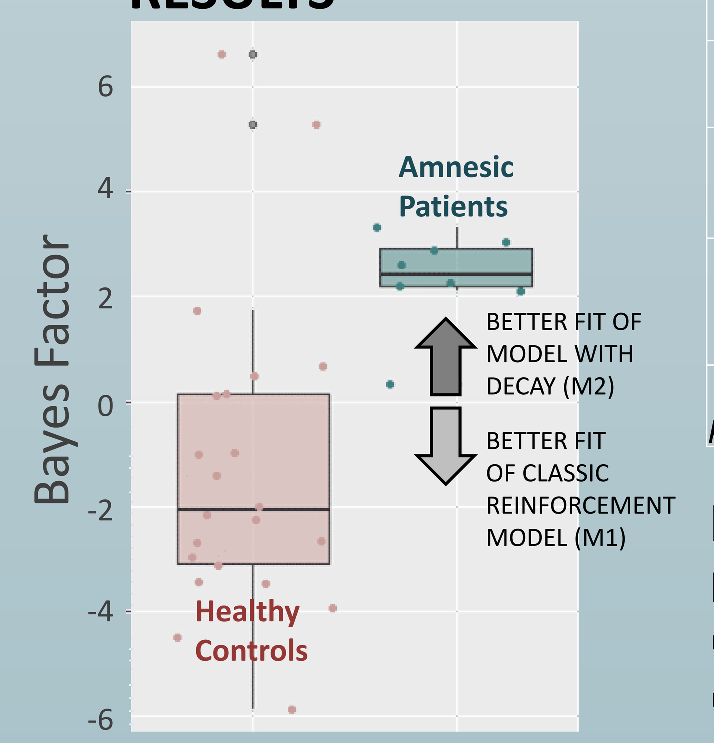
Etiologies: hypoxic-ischemic injury secondary to cardiac or respiratory arrest (n=4), stroke (n=2), encephalitis (n=1), and status epilepticus followed by left temporal lobectomy (n=1).

Demographics:
2 female/6 male
Age: 62.1 years (SD=7.4)
Education: 15.5 years (SD=2.7)

Healthy Controls (N=22)

Demographics:
12 female/10 male
matched in Age: 60.5 years (SD=11.0) and Education: 16.0 years (SD=2.9).

RESULTS



	Mean Parameters Model 2			Fit Comparison M2 vs. M1
	α (SD)	β (SD)	*decay* (SD)	Bayes Factor (SD)
Healthy Controls	0.23 (0.14)	4.2 (3.6)	0.10 (0.16)	-1.2 (3.0)
Amnesic Patients	0.17 (0.16)	1.8 (1.4)	0.50 (0.28)	2.3 (0.9)
p (t-tests)	*0.203*	*0.008*	*0.002*	*<0.001*

FINDINGS:

Response patterns were better fit
- without decay for control subjects
- with decay for amnesic patients

fMRI STUDY

PARTICIPANTS

Healthy Controls (N=30)

Demographics:
Right-handed
15 female /15 male
Native English speakers
Age: 19.6 years (SD=1.0)
Education: 13.2 years (SD=1.1)

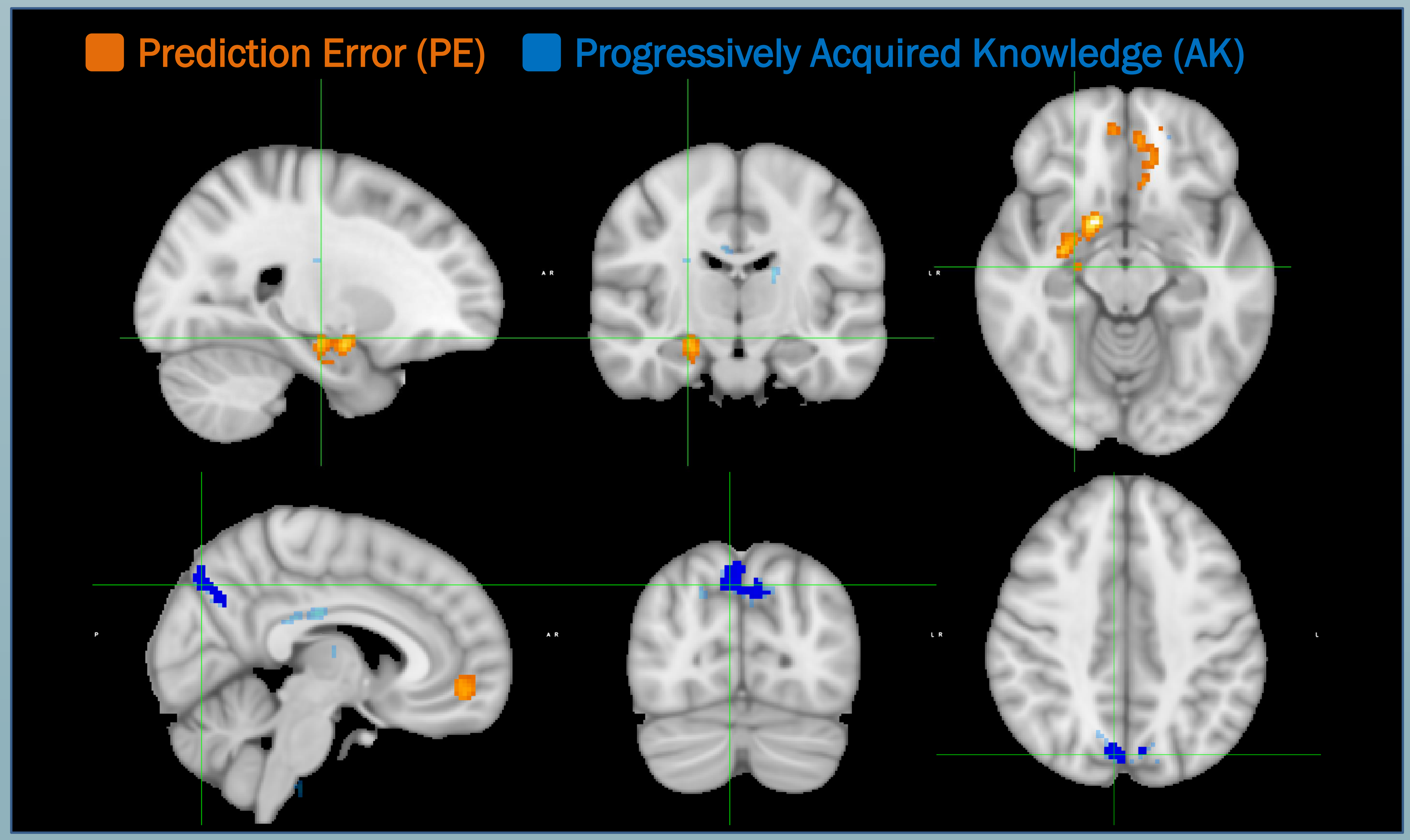
IMAGING ANALYSIS

Time series were computed for trial-by-trial prediction error (PE) and progressively acquired knowledge (AK), and were used as parametric modulators in a whole brain general linear model analysis (cluster-based threshold: p=.001, Software: FSL).

FINDINGS

- **Prediction Error (PE)** correlated with activation in the Anterior Hippocampus, Nucleus Accumbens, Putamen, Amygdala, & vmPFC.
- **Progressively Acquired Knowledge (AK)** correlated with activation in the Dorsal Precuneus & Middle Cingulate Gyrus.

RESULTS



DISCUSSION

(1) Response patterns of amnesic patients with hippocampal lesions were better fit by the model with decay, suggesting a critical role for the hippocampus in the maintenance of information during acquisition of response contingencies.

(2) PE correlated with activation in the anterior hippocampus, as well as with activation in the basal ganglia, amygdala, & vmPFC, suggesting that the hippocampus collaborates with regions typically involved in reinforcement learning.

(3) Dorsal precuneus & middle cingulate gyrus, key regions of the parietal memory network (PMN, Gilmore, Nelson, & McDermott, 2015), are involved in storing progressively acquired knowledge (AK) of stimulus-response contingencies.

(4) We postulate that the hippocampus may contribute to reinforcement learning by maintaining predictions about stimulus-response contingencies that ultimately are stored in cortical regions of the PMN.