Similarity-Based Episodic Memory Sampling Processes in Value-Based Decision-Making

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BACKGROUND

- Our decisions are often guided by past experiences.
- However, we do not always encounter the same choice situation again.

Reinforcement Learning & Episodic Memory

- The RL framework has limitations in explaining the complex and sparse nature of real-world decision environments (Gershman & Daw, 2017).
- Several studies have investigated how the values of single past episodes contribute to decisions, but it is unclear whether and how they contribute to the valuation of novel stimuli that never repeats.

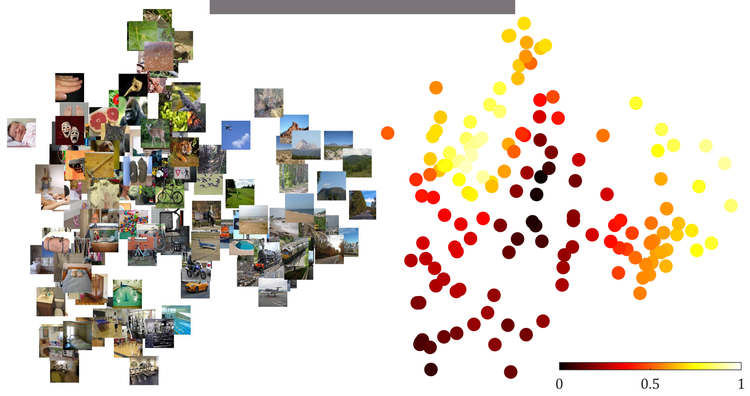
Case-Based Decision Theory

- The utilities of past experiences are weighted by their similarity to the current choice situation (Bhui, 2018).

CENTRAL HYPOTHESIS

Similarity plays a key role in enabling episodic memory to guide novel value-based decision-making.

METHODS



Stimuli

- 144 color images of complex naturalistic scenes and objects were taken from a prior study (King et al., 2019).

Reward Structure

- We utilized the representation of the CNN layer to quantify the similarity between the images.
- All images in the representational space of CNN layer were projected onto a 2-D space using multidimensional scaling (MDS).
- We assigned reward probabilities for all 144 stimuli to be unique while similar images had similar values.

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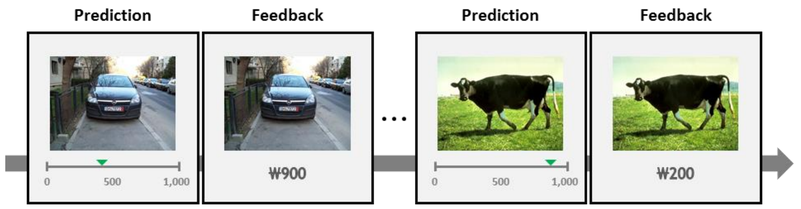
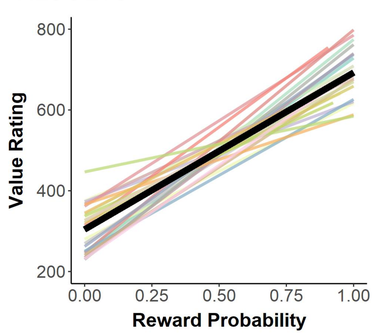
STUDY 1: BEHAVIORAL EXPERIMENT

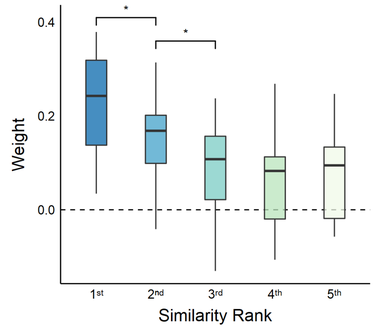
EXPERIMENTAL PROCEDURE



- On each of 144 trials, participants viewed a trial-unique naturalistic image and explicitly estimate the value of each novel image.
- The same images were never repeated, so participants had to infer the value based on the similarity structure.

RESULTS





Q. Can participants learn the reward structure?

- Value rating was significantly predicted by experimentally manipulated reward probability (β = 388, p < .001), such that the higher the reward probability assigned to the image, the higher the participants' value rating on that image.

Q. Does similarity affect the value estimation?

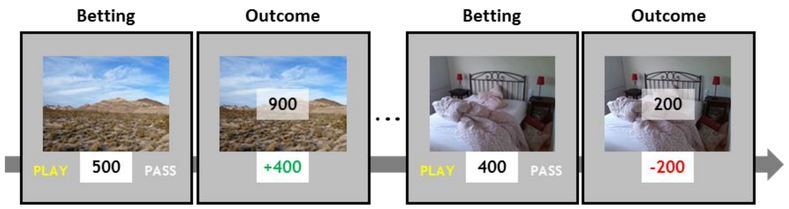
- We performed a multiple regression analysis predicting the value estimate in the current trial with the outcomes of the past 5 stimuli that are most similar to the current stimulus.
- Each of the outcome values of the 5 images had a significant effect on the value ratings (1st: $t(24)$ = 10.87, p < .001; 2nd: $t(24)$ = 7.12, p < .001; 3rd: $t(24)$ = 4.69, p < .001; 4th: $t(24)$ = 3.23, p = 0.004; 5th: $t(24)$ = 4.12, p < .001), and the regression weights were higher for the more similar stimuli.

REFERENCE

- Bhui, R. (2018). Case-based decision neuroscience: Economic judgment by similarity. In *Goal-Directed Decision Making* (pp. 67-103). Academic Press.
- Gershman, S. J., & Daw, N. D. (2017). Reinforcement learning and episodic memory in humans and animals: An integrative framework. *Annual Review of Psychology, 68*(1), 101-128.
- King, M. L., Groen, I. I., Steel, A., Kravitz, D. J., & Baker, C. I. (2019). Similarity judgments and cortical visual responses reflect different properties of object and scene categories in naturalistic images. *NeuroImage, 197*, 368-382.

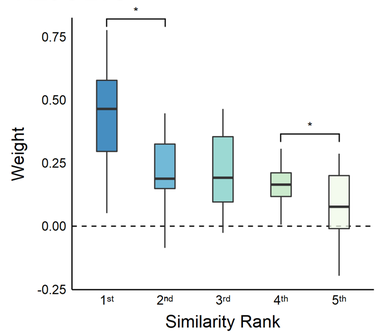
STUDY 2: fMRI EXPERIMENT

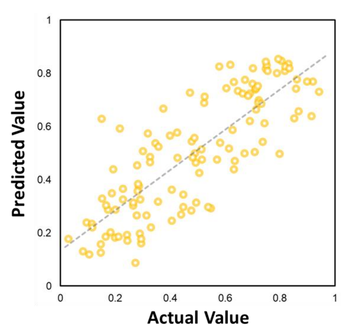
EXPERIMENTAL PROCEDURE



- Participants had to make decisions on whether to accept or reject each novel gamble based on the offer and the expected value of each image.
- Stimuli and reward assignment procedures were the same as in Study 1.

RESULTS

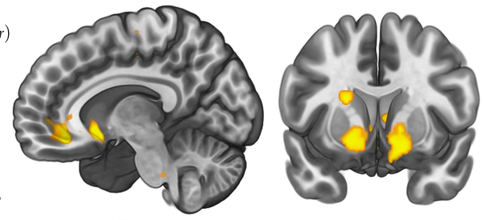




Computational Modeling

- Choice behavior could be predicted by our computational model, which was borrowed from Case-Based Decision Theory.

- $V(a) = \sum_{(q,a,r)\in M} \frac{s(p,q)}{\sum_{(q',a,r)\in M} s(p,q')} u(r)$



Model-Based fMRI Analysis

- Ventromedial prefrontal cortex (VMPFC) activity was correlated with the expected value of the chosen option.
- Ventral striatum activity was associated with the reward prediction error.

CONCLUSIONS

- Our findings provided empirical evidence that similarity plays a key role in enabling episodic memory to guide value-based decision-making.
- We provided the neural and computational mechanisms underlying the value computation through similarity-based episodic sampling processes.