Spotlight
Decoding social rewards via inter-areal coordination frequency in the brain
Masaki Isoda

Vicarious reward plays a pivotal role in shaping altruism and prosociality. However, neural circuit mechanisms underlying the distinction between vicarious reward and experienced reward are poorly understood. Putnam et al. recently demonstrated that the two types of reward are represented by distinct coordination frequencies within the same cingulate–amygdala pathway.

Imagine that you are faced with a choice between two options in two different contexts (Figure 1A). In the first context, you must choose between options O and N. If you choose O, you receive $0 whereas a person in front of you gets $4. However, if you choose N, no one gets any money. In the second context, you must choose between options S and B. If you choose S, you receive $4. However, if you choose B, both get $4. Which option would you then choose in each context?

In the above scenario you will find that your own outcome is exactly the same regardless of which option you choose – in other words, a 0% and 100% probability of reward in the first and second contexts, respectively. However, the outcome for the other person differs entirely depending on your choice. Arguably, your decision will be guided by your other-regarding preferences. An indirectly experienced reinforcement by observing the outcome for another person – also known as vicarious reward – plays a role in determining various types of prosocial behaviors such as empathy and altruistic behavior.

It has been advocated that similar neurocomputational algorithms underlie the processing of vicarious reward and directly experienced reward [1]. In support of this idea, both types of reward elicit activation in overlapping brain regions [2]. However, the activation of common regions does not necessarily mean that the neural substrates for the two reward processes are identical at a finer-grained level such as single neurons and neural pathways. This issue is also important at the conceptual level because determining the optimal level of cooperation and reciprocity depends on the distinction between vicarious and experienced rewards. A dorsal portion of the medial prefrontal cortex contains single neurons that specifically encode behavioral information (e.g., action and reward) about the self and other [3]. Then, could social agents be directly or vicariously rewarded via distinct firing dynamics within a single neural pathway? A recent primate electrophysiological study provides novel evidence for a role of the pathway linking the anterior cingulate cortex (ACCg) and the basolateral amygdala (BLA) in differentiating vicarious from experienced rewards using different inter-areal coordination frequencies [4].

Putnam et al. [4] trained two adult macaques to perform a social reward allocation task. The essence of the task is described in the scenario above. The only difference is that a reward was a drop of juice instead of money. One animal was assigned the role of actor, and the other was a non-actor, and their roles were never swapped. The two animals were not cagemates but had multiple social interactions during the task owing to the chronic experimental design. During each trial the actor was required to make a choice by making an eye movement. The two contexts of decision-making (O–N and S–B) were randomly interleaved.

In the O–N context, the actor gave preference to O over N. Moreover, the larger the reward size, the greater the number of trials conducted by the actor. Thus, the actor showed a positive other-regarding preference based on vicarious rewards. In the S–B context, however, the actor preferred S over B, displaying a negative other-regarding preference. In this task it is difficult to understand why such opposing preferences emerge in a context-dependent manner. Nevertheless, similar results have been obtained in different animals in independent studies [5,6].

Putnam et al. recorded spikes of single neurons in the ACCg and, simultaneously, local field potentials in the BLA (Figure 1B, left). They then computed spike-field coherence (hereafter ACCg_{spike–BLA_{field}} coherence) to determine the coordination between the two regions. In an attempt to identify dissociable neural signals of vicarious and experienced rewards, ACCg_{spike–BLA_{field}} coherence was contrasted between O and N for vicarious reward and between S and N for experienced reward. The authors found that, immediately after reward onset, ACCg_{spike–BLA_{field}} coherence was increased only for vicarious reward (Figure 1B, right). By contrast, ACCg_{spike–BLA_{field}} coherence in the alpha/beta frequency range (10–20 Hz) increased only for experienced reward (Figure 1B, right). These results suggest that information about vicarious and experienced rewards is represented in the same neural circuit but uses different coordination frequencies.

Further analyses helped to clarify whether increased coherence was associated with reward outcome. To this end, the experimenters introduced forced-choice trials in which the same reward outcomes occurred without choice of the actor. Surprisingly, the difference in ACCg_{spike–BLA_{field}} coherence between the two types of rewards was now much less clear in both low gamma and alpha/beta
Trends in Cognitive Sciences

bands. Thus, increased coherence was selective for the reward outcomes derived from commitment to a decision. A further test using Granger causality confirmed that social reward information predominantly flowed in a top-down direction, a finding consistent with prior work under different task conditions [7].

The study by Putnam et al. raises many additional questions. First, their study addressed only a positive (appetitive) outcome. It has been shown that neurons in the rat ACC respond to vicarious and experienced pain [8]. Are the two types of negative (aversive) outcomes also represented in the ACC—BLA pathway via distinct coupling dynamics? Second, the frequency-specific increase in the ACCspike—BLAfield coherence is correlational. It is not clear what roles they play in actual social decision-making. Pathway-selective blockade using viral vectors is technically feasible [9], but to do so in a frequency-specific manner would be challenging. Finally, to what extent is the coding of social agents via distinct coupling dynamics in the same neural pathway versatile? Does it extend beyond the reward domain? For example, can we make a clear distinction between executed and observed actions by observing the inter-areal coherence in a particular neural pathway?

Despite these caveats, Putnam et al. provide compelling evidence for a novel neural code for social reward allocation. By monitoring ACCspike—BLAfield coherence and tuning the dial to specific frequency channels, experimenters can decode an actor’s decision about whether to give a reward to others or keep it for themselves (Figure 1C).

Acknowledgments

This work was supported by the Japan Agency for Medical Research and Development (JP19dm0307003) and grants-in-aid from the Japan Society for the Promotion of Science (22H04931).

1Division of Behavioral Development, Department of System Neuroscience, National Institute for Physiological Sciences, National Institutes of Natural Sciences, Okazaki, Aichi 444-8685, Japan
2Department of Physiological Sciences, School of Life Science, Graduate University for Advanced Studies (SOKENDAI), Hayama, Kanagawa 240-0193, Japan

*Correspondence: isodam@nips.ac.jp (M. Isoda).

https://doi.org/10.1016/j.tics.2023.07.010

References


Figure 1. Schematic illustration of key procedures and findings. (A) Essence of the social reward allocation task. (B) Main findings of the work by Putnam et al. [4]. Abbreviations: ACC, anterior cingulate cortex gyrus (yellow ellipse); BLA, basolateral amygdala (green ellipse). Spike-field coherence between ACC spikes and BLA local field potentials (ACCspike—BLAfield coherence) shows an increased vicarious reward contrast (O minus N, blue line) in the low gamma band and an increased experienced reward contrast (S minus N, orange line) in the alpha/beta band. (C) Specific frequency channels in the ACC—BLA pathway carry social agent information in the domain of reward.