

# **The Role of the Primate Mediofrontal Cortex in Evaluation and Integration of Gains and Losses**

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Outcomes of decisions are evaluated as positive or negative, even when reward can be obtained only through a series of state transitions. Nevertheless, the neural mechanisms responsible for evaluating such state transitions are largely unknown. In this study, we recorded the activity of neurons in the dorsal anterior cingulate cortex (ACCd) and the overlying dorsomedial prefrontal cortex (DMFC) of rhesus monkeys performing an oculomotor binary decision-making task involving such multiple state transitions.

Throughout the experiment, the center of a computer screen displayed a variable number of red disks that indicated a particular state. The number of disks increased (forward state transition), decreased (backward state transition) or remained unchanged (no transition) according to the payoff matrix of a biased matching pennies game. The animal was rewarded with 6 drops of juice, when it reached the final state of 6 disks. The animal began each trial by fixating a square at the center of the screen, and two peripheral targets were presented along the horizontal meridian. When the central square was extinguished after a 0.5 s-delay period, the animal was required to shift its gaze towards one of the two targets. After a 0.5-s hold period, the outcome of the animal's choice was revealed by the color of a feedback ring presented around the chosen target. Choosing one of the targets (safe target) led to a forward or no transition, whereas the other target (risky target) led to a forward or backward transition. The forward transition occurred only when the animal selected the same target as the computer, which was programmed to simulate an opponent in the biased matching pennies game. The optimal strategy for the animal was to choose the safe target with a 2/3 probability. The safe and risky targets changed their positions unpredictably after a minimum of 40 trials.

Behavioral data from the two monkeys showed that the probability of choosing a particular target was systematically influenced by the direction of state transitions resulting from their previous choices. Neural activity during delay and feedback periods were analyzed using a multiple linear regression model, in which the spike count during the 0.5-s delay and feedback period was modeled as the function of the animal's choices and their outcome in the current and multiple previous trials. In many neurons, the activity during the feedback period was modulated by forward state transition (80% and 76% in DMFC and ACCd, respectively), backward state transition (58% and 41% in the DMFC and ACCd), or both (42% and 35% in DMFC and ACCd), suggesting that these areas might be involved in evaluating gains and losses. Furthermore, activity of some neurons in DMFC (26%) and ACCd (20%) encoded forward and backward transitions by changing their activity in opposite directions, suggesting that they might encode outcome utilities. Activity during delay and feedback periods was also modulated by the animal's choices and outcomes in the multiple previous trials. For example, 34%, 44% of the neurons in the DMFC and the ACCd modulated their activity for the previous gain, respectively, and 56% and 36% for the previous loss. These results suggest that the primate mediofrontal cortex might play a key role in evaluating the state transitions resulting from the animal's actions and integrating this information across multiple trials for optimal decision-making strategy.

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