論　文　概　要

○ 論 文 題 目

Signal dynamics of midbrain dopamine neurons and orbitofrontal neurons during economic decision-making in monkeys.

（経済的意思決定時のサル中脳ドーパミンニューロンおよび眼窩前頭皮質の信号ダイナミクス）

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Purpose: In economic decision-making, individuals first evaluate the value of options, and then decide to choose or not to choose the options based on the value. To identify the neural mechanism underlying this behavior, it is critical to understand how the brain transforms value information into choice commands. Although cortical information processing has attracted attention as the neural substrate underlying the value-to-choice transformation, roles of subcortical structures in the transformation process remains unclear. In the present study, I addressed the role of dopamine neurons, a subcortical hub for value processing, in the transformation process by investigating what decision variables dopamine neurons represent and how their signals evolve during economic decision-making in monkeys.

Material and method: I used two adult rhesus monkeys as experimental animals. I trained them to perform an economic decision-making task in which the monkey was required to decide to choose or not to choose an option based on its value immediately after the option was offered. When the monkeys were performing the task, I recorded single-unit activity from 96 dopamine neurons. In addition, I also recorded activity from 285 neurons in the orbitofrontal cortex (OFC), which has been implicated in value-to-choice transformation, to characterize the role of dopamine neurons in the transformation process by comparing dopamine and OFC neuron activities.

Result: First, I found that as well as OFC neurons, dopamine neurons represented diverse signals related not only to the option's value but also to the animal's choice; some neurons represented the value of the offered option, some represented whether or not the animal

would choose the option, and some represented the value of the option only when the option was chosen by the monkey -an intermediate signal that was influenced by both value and choice. I next analyzed the time course of these dopamine signals and found that the order of signal representations corresponded to the value-to-choice transformation. Shortly after the onset of the option, the value-modulated signal rapidly appeared, which was followed by the intermediate signal. The choice-modulated signal arose at last. Such signal dynamics was also found in OFC neurons. Notably, the last-arising choice signal appeared before the monkey executed a motor action to choose the option in both dopamine and OFC neurons. Thus, both neurons were capable of regulating the monkey's choice behavior. On the other hand, the choice-modulated signal of dopamine neurons preceded that of OFC neurons, indicating that the transformation process is completed earlier in dopamine neurons than in OFC neurons. Furthermore, using a simple motor task in the same monkeys, I revealed that the choice signal of dopamine neurons did not simply reflect the monkey's motor action itself.

Discussion: Previous studies have proposed that the role of dopamine neurons in economic decision-making is to reinforce choices leading to better outcomes than predicted by transmitting a value-related signal called reward prediction error (RPE). Contrary to this theory, I found that the activity of dopamine neurons directly reflected the animal's upcoming choice, and that the dopamine signal dynamics corresponded to the value-to-choice transformation. These results suggest that beyond the way to mediate choices through the effect on reinforcement, dopamine signals might be directly involved in value-based decision formation. Based on dopamine direct projections to the prefrontal cortex and the cortico-basal

ganglia circuitry, it could be possible that the dopamine choice signal is sent to the cortex to mediate cortical information transformation processes, as well as that the dopamine signal directly regulates choice behavior generation or expression through basal-ganglia pathways. Further studies are called for to determine how the dopaminergic circuitry cooperates with other components of the decision-making system, including the OFC, to form economic decisions.

Conclusion: In the present study, I found that dopamine neurons, as well as OFC neurons, represented multiple signals related not only to the option's value but also to the monkey's upcoming choice while the animal was making an economic decision. These signals exhibited a temporal profile corresponding to value-to-choice transformation. The signal transformation completed earlier in dopamine neurons than OFC neurons, suggesting dopamine neurons are a strong subcortical candidate that leads value-to-choice transformation as a part of the distributed decision-making system.