## Press Release





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# Anticipation of the future shapes self-controlled choice —The human brain awaiting a reward that have not ever been experienced—

Daiki Tanaka, a former graduate student and Dr. Koji Jimura, an associate professor at Keio University, Dr. Shinsuke Suzuki, an associate professor at the University of Melbourne, and Drs. Kiyoshi Nakahara, a professor, Masaki Takeda, a professor, and Ryuta Aoki, a research associate, at Kochi University of Technology, discovered that the prefrontal cortex of the human brain is associated with anticipations of favorable future events that have not been experienced ever. The prefrontal mechanism was enhanced in individuals forming greater degree of self-controlled preference based on past experiences. The current study suggests that in situations without past experiences, anticipation of the future events enables long-term optimal behavior. The prefrontal cortex mechanisms involved in future anticipations are implicated in psychopathology such as drug and alcohol abuses. This study was published in the December 9 edition of the Journal of Neuroscience issued by the Society for Neuroscience.

## 1. Main Points of Research

- Using real juice as a reward, human brain activity was measured in situations where the reward became available in the future after a short delay (~60 sec).
- While an unexperienced reward was awaited, the prefrontal cortex showed dynamic brain activity reflecting the anticipation of the future.
- The prefrontal cortex activity was stronger in individuals with greater self-controlled preference.

#### 2. Background of Research

If you could get 5,000 yen now or 10,000 yen in one year, which would you like? This question can be formulated whether one prefers a smaller amount of reward available immediately or a larger amount of reward available after a delay, which is referred to as intertemporal choice in behavioral economics. Individuals who prefer the former and latter are characterized as impulsive and selfrestrained (self-controlled), respectively. It is known that greater self-control allows individuals to maximize reward attainments in the long term (Figure A). Impulsiveness and self-control regulate our daily financial decision-making and feeding behavior, but are also associated with psychopathology such as drug/alcohol abuses and obesity.

Intertemporal choice has been studied in non-human animals and humans. Most of human experiments have used hypothetical choice situations for delayed monetary rewards, while nonhuman experiments have used real choice situations for food and liquid rewards where the animals directly experience the delay and consume (eat, drink) the rewards. Additionally, in nonhuman animal experiments, choice preference was formed based on the direct experiences during the experiments, whereas in human experiments, the preference was presumed to be formed prior to the experiments. These discrepancies in experimental procedures in human and non-human animal studies have limited our understanding of impulsiveness and self-control. In particular, in human studies, it was unclear how choice preferences were formed and what happens in the brain while humans were awaiting for rewards that had not ever been experienced (Figure A).

#### 3. Content of Research and Results

In this study, Tanaka's team applied the experimental procedures of intertemporal choice that have used in non-human animals to a human experiment. Using functional MRI (\*1), brain activity was measured while humans were awaiting real liquid rewards (juice) that have not ever experienced, and then consumed the reward.

During functional MRI scanning, human participants first experienced a real liquid (juice) reward that became available after tens of seconds (delayed reward; Figure B, red circles). Next, they experienced smaller amount of juice reward available immediately (immediate reward; Figure B, blue star). Then, they were asked to choose one of the two options as they preferred. It is important that when the participants experienced the delayed reward for the first time, they had not ever experienced the reward; they did not know when the juice reward would become available.

In order to model the degree of participants' anticipation while they were awaiting for the delayed reward have not been experienced, anticipatory utility model (\*2) was used based on a behavioral economics theory (Figure C). Anticipatory utility is thought to reflect the "pleasure of the wait itself."

Then, brain regions were explored where the activity reflected anticipatory utility while participants were awaiting reward, and a polar region in the prefrontal cortex was identified (Figure D, black arrow). Importantly, in this



region, activity reflecting anticipatory utility was stronger in individuals who made more selfcontrolled choices (greater preference for larger amount of delayed rewards against smaller amount of immediate rewards; Figure E).

While participants consumed the rewards (drank the juice), if a brain region called ventral striatum that locates in a deeper region of the brain became highly active, then subsequent choice preference became more impulsive (preference for smaller amount of immediate reward). Additionally, while the delayed reward was anticipated, the ventral striatal received inhibitory regulation from the prefrontal cortex, which was enhanced in individuals with greater self-control.

These results suggest that strong self-controlled choice preference is formed by a greater prefrontal activity reflecting anticipation of favorable future events that has not ever been experienced, which allows humans to behave optimally to maximize reward attainment in the long term. The anticipation signals in the prefrontal cortex inhibit activity in the ventral striatum that have evolutionarily been conserved and is associated with impulsivity of human behavior.

Among diverse species of animals that make intertemporal choices, the polar region of the prefrontal cortex is most developed in humans. It is interesting that the function of anticipation of happy events occurring in the unknown future is observed in this region of the brain, demonstrating a disposition of humans. The nature of the prefrontal function involved in the anticipation of a happy future, which guides humans to make self-controlled choices based on past experiences, may provide important insights to extend our understating of mental disorders such as drug and alcohol abuses.

#### 4. Future Developments

This study makes it possible to directly compare brain functions involved in intertemporal choice among animal species including humans. The comparisons with non-human animals in which novel neuroscientific techniques are more available may extend our understanding of the nature of humans anticipating a happy future. More broadly, this study would lead to a deeper understanding of the biological nature of human financial decision-making and its deficits. Additionally, it is also possible to examine brain mechanisms associated with alcohol abuse and obesity, which may be linked to behavioral impulsivity, using other directly consumable rewards such as alcoholic beverages and food.

#### <Details of Journal Article>

Tanaka D, Aoki R, Suzuki S, Takeda M, Nakahara K, Jimura K (2020) Self-controlled choice arises from dynamic prefrontal signals that enable future anticipation. J Neurosci 40:9736-9750 doi: 10.1523/JNEUROSCI.1702-20.2020.

#### <Glossary>

\*1 Functional MRI

A non-invasive method to measure physiological signals related to neuronal activities that covers the entire brain. It was developed by physicists Drs. Seiji Ogawa and others.

## \*2 Anticipatory utility

An economic theory of utility (value) explaining that anticipation of a favorable future event itself has a value. For example, given that one plans a travel on a vacation in the next year, thinking about the travel itself involves a pleasure. The anticipatory utility reflects such a pleasure of wait for a reward. The theory was proposed by the behavioral economist George Loewenstein.

\*Please direct any requests or inquires to the contact information provided below in advance.

\*This news release has been sent to the MEXT Press Club, the Science Press Club, and the science sections, etc., of other media outlets.

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