Self-control Signals in the Supplementary Eye Field of Monkeys during a Temptation Task

Jaewon Hwang[1] , Erik E. Emeric[1] & Veit Stuphorn[1,2]

[1]Zanvyl Krieger Mind/Brain Inst., Johns Hopkins Univ., Baltimore, MD; [2]Dept. of Neurosci., Johns Hopkins Univ. Sch. of Med., Baltimore, MD

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Introduction

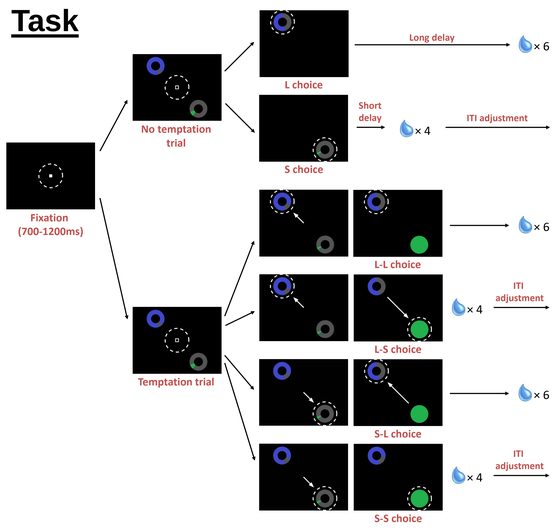
Self-control is the ability to resist short-term temptations in order to achieve long-term goals. The intertemporal choice task measures subjective preference for large, later rewards against small, sooner rewards and hence self-control. However, in this task, the effect of self-control on the relative value of each option cannot be dissociated from other factors influencing their value, such as the relative difference in reward amounts and delays, and the relative weight given to each factor. To address this issue, we trained monkeys to perform a variant of the intertemporal choice task, which we call the temptation task, and monitored the activity of neurons in the supplementary eye field (SEF).

Methods

After a variable fixation period, the subjects were required to choose between two targets that resulted in either a large, long-delayed reward (L) or a small, short-delayed reward (S). Each target contained a colored segment. The length and the color of the segment indicated the delay and the amount of the reward, respectively. The subjects were reinforced for fixating the selected target while the colored-segment decreased in length at a constant angular speed until the annulus was completely gray. In no-temptation trials, the target that was not chosen disappeared once a choice was made. In temptation trials, however, the unchosen target remained present during the waiting period and the subjects were allowed to change their choice before the initially selected reward was delivered. After the delay of an unchosen S target had elapsed, it was replaced with a filled circle of the same size and color, indicating that the reward would be given immediately upon switching. These two types of trials were selected pseudo-randomly every trial.

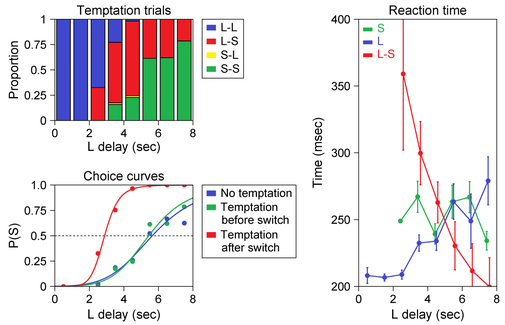
Stimuli

Task



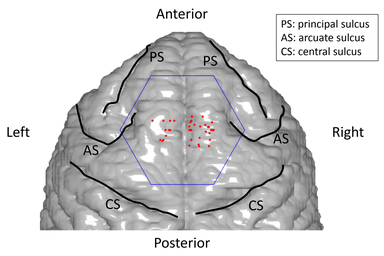
Results

❑ Behavioral performance



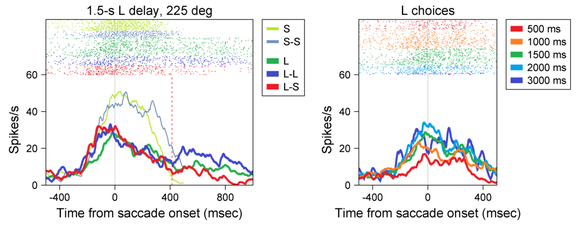
During the temptation trials, the subjects often chose the L target and kept the choice to the end (L-L choice). However, they sometimes switched to the S target while waiting for delayed reward (L-S choice), which indicates a failure of self-control. In the L-S choices, the time to switch from L to S increased with decreasing L delay, suggesting that the subject hesitated more when the relative value of the tempting S target was smaller.

❑ Recording of neural activity



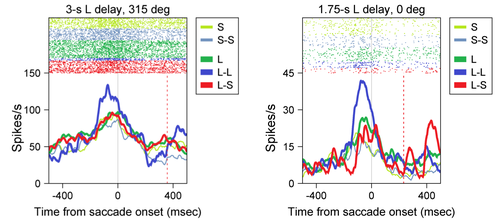
The SEF is located on the dorsomedial surface of the frontal lobe. Single-unit activity was acquired bilaterally from the SEF of two subjects, using a multi-electrode recording system.

❑ Neuron that encode values



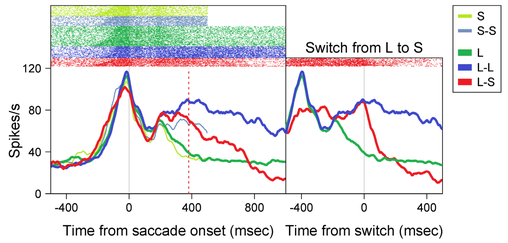
The neuron shown in the above figure responded differently depending on whether the subject initially chose the small, short-delayed reward or the large, long-delayed reward (left panel). There was no difference in activity between trials in which the subject maintained the initial choice (L-L) or not (L-S). Therefore, the neuron above encodes the value of the initially chosen target. This is confirmed by grouping all the L choice trials according to the delay of the L targets (right panel).

❑ Neurons with self-control signals



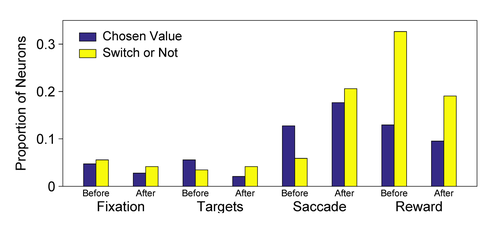
Some SEF neurons showed enhanced activity around the time of the saccade when the subjects chose the L option and maintained it (L-L choice). However, these enhancements were not observed when the subjects gave in to temptation (L-S choice), although the target configuration was identical. Therefore, this activity seems related to self-control.

❑ Neuron with persistency effect



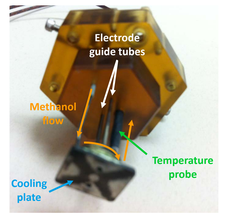
This neuron exhibited sustained activity during the waiting period, but only when the subject maintained the large-reward choice against the temptation of the small reward (L-L choice, blue). When there is no temptation (L-choice, green) or the subject gave up the large reward (L-S, red), the activity decreased immediately.

❑ Effects of task variables



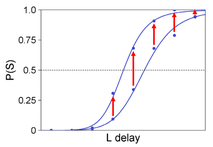
The effects of the chosen value and self-control during the temptation trials were tested using a regression model for all the recorded neurons (N = 191). The proportion of the neurons that represented the chosen value increased from the saccade preparation period, whereas most of the activity related to self-control occurred within 300ms after the initial saccade. The activity during the reward period seems to reflect the amount of the received reward which differed as the result of the choice switch.

❑ Cooling experiment

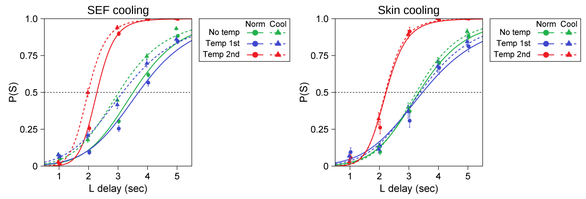


- To test whether there is a causal relationship between the SEF activity and the self-control behavior, we performed cooling experiments with the temptation task.
- Normal temperature blocks (37˚C) and cooling blocks (4-9˚C) were alternated every ~20 minutes, while the subjects performed the task.

❑ Decreased self-control during SEF cooling



- The reduced self-control will shift the choice curves in our figures leftward, because the subjects will choose the small, short-delayed rewards more often.



During the SEF cooling, we found that the choice curves shifted leftward in the cooling blocks, compared to the normal blocks ($p<0.001$). However, such a shift was not observed when cooling was performed on the scalp ($p>0.474$).

Conclusions

1. Our temptation task can detect the trial-by-trial success of self-control by monitoring whether the subject maintains the choice of a large but delayed reward or gives in to the temptation of a small but immediate reward.
2. Two different types of SEF neurons show activity related to self-control behavior. One type of the neurons seems to be involved in resisting temptation at the stage of making a choice and the other type, in maintaining the initial choice during the waiting period.
3. The results of our cooling experiments show that SEF is causally related with self-control behavior.

Acknowledgement

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