

## Role of serotonin in delayed reward choice in humans

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Although deregulation of the neuromodulator serotonin has long been implicated in disorders such as depression and impulsivity, its normal function in the human brain has remained enigmatic. In animals, decreased serotonin levels increase impulsive choice[1,2], presumably via an increase in the rate of discounting[2], which renders large delayed rewards less valuable than small immediate rewards. Here, we studied the effect of serotonin manipulation in humans in computer tasks in which subjects must choose between a more immediate small reward and a large delayed rewards at each trial; in these tasks, each choice affects the time remaining for later trials, and the delays vary at each trial.

We first studied the shape and the steepness of the reward discounting function adopted by our subjects in the control serotonin condition. We demonstrated that most of our subjects adopted exponential discounting in this experiment[3]. Further, we showed analytically that exponential discounting, with a decay rate comparable to that used by our subjects, maximized the total reward gain. Our results suggest that the particular shape and steepness of temporal discounting is determined by the task that the subject is facing, and question the notion of hyperbolic reward discounting as a universal principle.

Then, by using a computational model of delayed reward choice learning, we estimated the parameters governing the subjects' choice behavior in low, normal, and high serotonin conditions. We found an increase in the rate of discounting of delayed rewards in the low serotonin condition compared to the control and the high serotonin conditions. Neither the speed of learning of the reward values, nor the variability of choice were affected by serotonin levels, however. Our findings confirm the role of serotonin in evaluating delayed rewards in humans, a role previously suggested in animal studies.

Finally, we performed a fMRI experiment to elucidate the neural mechanisms of serotonin in the evaluation of delayed rewards. A model-based analysis showed that the activity of the ventral part of the striatum correlated with reward prediction at shorter time scales, and that this activity was stronger at low serotonin levels. In contrast, the activity of the dorsal part of the striatum correlated with reward prediction at longer time scales, and this activity was stronger at high serotonin levels. Our result suggests that serotonin controls the time scale of reward prediction by differentially regulating striatal activity.

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### References

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