

Supplemental Materials

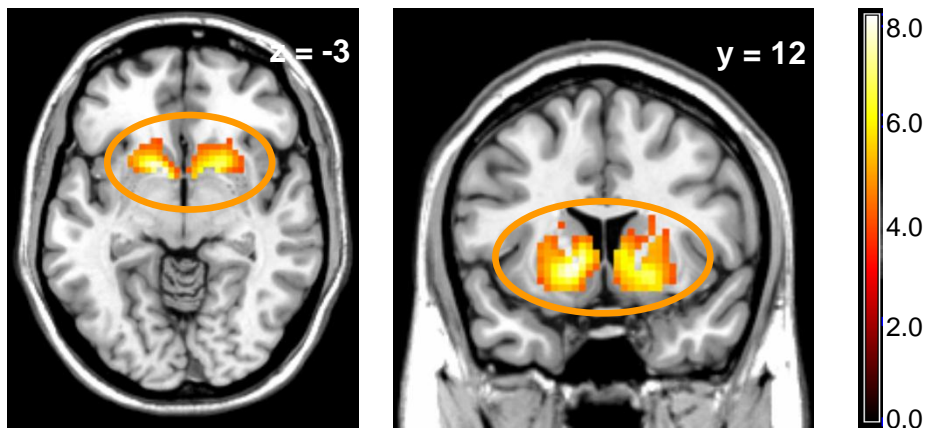
Consolidation Power of Extrinsic Rewards: Reward Cues Enhance Long-Term Memory
for Irrelevant Past Events

Kou Murayama

University of California, Los Angeles

Shinji Kitagami

Nagoya University



Supplementary Figure 1. Bilateral striatum showing significant activation in response to the stopwatch task cues relative to the control task cues ($p < .05$, family-wise error corrected; the image is shown at $p < .001$, uncorrected) based on the reanalysis of the data presented in Murayama, Matsumoto, Izuma, and Matsumoto (2010). Neural responses are displayed in transaxial and coronal formats.

Supplementary Results

To examine whether a task cue that signals the stopwatch task enhances the phasic activation in the striatum, which is a core region of the dopaminergic reward system (Haber & Knutson, 2010; Shohamy, 2011), we reanalyzed the brain imaging data reported in our previous study (for procedural details, see Murayama, Matsumoto, Izuma, and Matsumoto, 2010). In that study, participants were presented with both stopwatch task and control task in a random sequence, and only the stopwatch task was rewarded. Therefore, the experimental situation was quite analogous with the current experiment, with the exception that this experiment did not include any learning materials to test memory performance. We used the data from the reward group in the first session, as this is the only condition where monetary reward was provided contingent on task performance ($N = 14$). Functional imaging was conducted using a 3 Tesla Siemens Trio A Tim MRI scanner to acquire gradient echo T2* weighted echo-planar images (EPI) with blood oxygenation level dependent (BOLD) contrasts.

We anatomically defined the striatum as a priori regions of interest (ROIs) by using the WFU-Pickatlas SPM toolbox (Maldjian, Laurienti, Kraft, & Burdette, 2003). The ROI consisted of the bilateral caudate and putamen in the AAL atlas. The general linear model contrasting the periods of reward task cue with control task cue revealed very strong activation in the bilateral striatum ($p < .05$, $k > 100$; family-wise error corrected; see Supplementary Figure 1). These results suggest that the reward task cue used in the current study could reliably activate the striatum, a core region of the dopaminergic reward system.

We further examined activation in the amygdala. We anatomically defined the amygdala as a priori ROIs by using the WFU-Pickatlas SPM toolbox (Maldjian et al., 2003). The ROI consisted of the bilateral amygdala in the AAL atlas. The general linear model contrasting the periods of reward task cue with control task cue did not show any single significant activation either with conventional ($p < .05$, family-wise error corrected) or more lenient criteria ($p < .001$, uncorrected). Given that the amygdala is a primary brain region related to emotional arousal (e.g., Small et al., 2003), these results may suggest that emotional arousal is unlikely the source of the postencoding memory enhancement effect observed in the current experiment.

These two findings accord with the possibility that dopaminergic activation in the brain may have promoted the retrograde memory enhancement effects observed in our study. However, we must be cautious when speculating psychological processes from neuroimaging findings (Poldrack, 2006).

Supplementary References

Haber, S. N., & Knutson, B. (2010). The reward circuit: Linking primate anatomy and human imaging. *Neuropsychopharmacology*, *35*, 4–26.

Maldjian, J. A., Laurienti, P. J., Kraft, R. A. & Burdette, J. H. (2003). An automated method for neuroanatomic and cytoarchitectonic atlas-based interrogation of fMRI data sets. *Neuroimage*, *19*, 1233–1239.

Murayama, K., Matsumoto, M., Izuma, K., & Matsumoto, K. (2010). Neural basis of the undermining effect of monetary reward on intrinsic motivation. *Proceedings of the National Academy of Sciences of the United States of America*, *107*, 20911–20916.

Poldrack, R. A. (2006). Can cognitive processes be inferred from neuroimaging data? *Trends in Cognitive Sciences*, *10*, 59–63.

Shohamy, D. (2011). Learning and motivation in the human striatum. *Current Opinion in Neurobiology*, *21*, 408–414.

Small, D. M., Gregory, M. D., Mak, Y. E., Gitelman, D., Mesulam, M. M., & Parrish, T. (2003). Dissociation of neural representation of intensity and affective valuation in human gustation. *Neuron*, *39*, 701–711.