The Role of Dopamine in Value-Based Attention as Revealed by Positron Emission Tomography

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Background & Motivation

Stimuli previously associated with reward draw attention regardless of intention[1-4]. Dopamine release within the dorsal striatum has been linked to habitual behaviors[5] and drug craving[6,7], which could be related to automatic attention processes. Nonspecific measures of brain activity have implicated the striatum in value-based attention[3,4]; however, the neurochemical mechanisms underlying value-based attention remain unexplored. Here, we investigated the contribution of dopamine to value-based attention using positron emission tomography (PET) with [11C]raclopride.
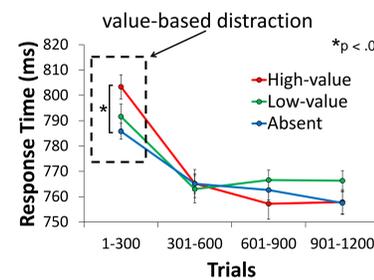
Training Phase:
Participants Learn Color-Reward Associations

- **Participants:** 20 neurologically healthy adults (10 female, 18-31 y, mean = 23.4 y).

- **Timeframe:** Evening prior to PET scanning.

- **Task:** Find the color-defined target on each trial and report the orientation of the bar within the target as either vertical or horizontal via a button press.

- **Visual Search Target:** Red or green circle. Only one target circle is presented on each trial, equally-often in each color.

- **Reward Manipulation:** Following a correct response, money is added to a bank total in the reward-feedback display. One of the two target colors (counterbalanced across participants) is followed by a high reward of $1.50 on 80% of the trials on which it is correctly reported, and by a low reward of 25¢ on the remaining 20% of correct trials (high-value color); for the other (low-value) color, these mappings are reversed.
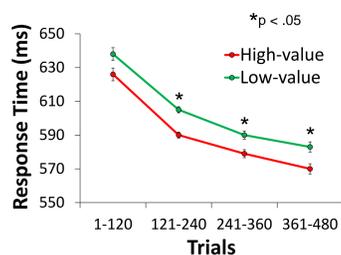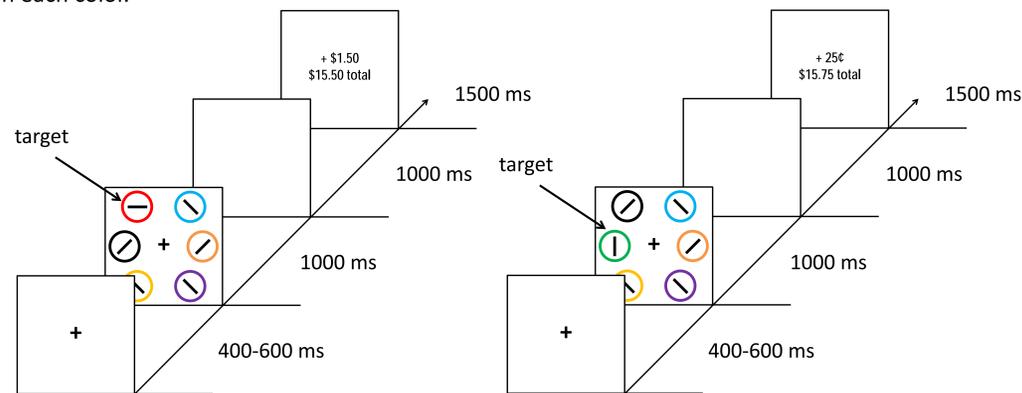
Faster responses to the high-value target indicate learning of the color-reward associations

Test Phase:
The Consequence of Reward Learning on Attention is Examined

- **Timeframe:** The same participants perform the test phase over the course of two PET scans (order counterbalanced, see below).

- **Task:** Find the shape-defined target on each trial and report the orientation of the bar within the target as either vertical or horizontal via a button press. Participants are informed that color is now irrelevant to the task. On some trials, one of the non-targets is rendered in a previously reward-associated color (referred to as a **valuable distractor**).

- **Visual Search Target:** Shape singleton (diamond among circles or circle among diamonds, equally-often).

- **Feedback:** No trial-by-trial feedback about performance is delivered.

Distractor Absent Scan   ### Distractor Present Scan

100% of trials   50% of trials   25% of trials   25% of trials
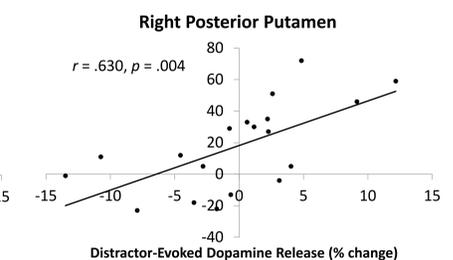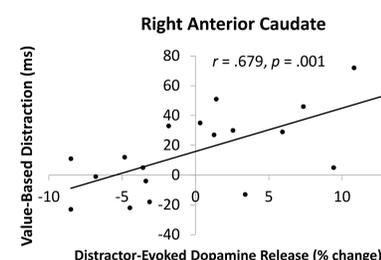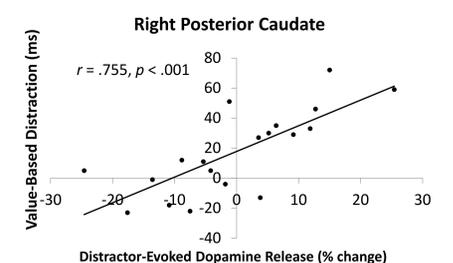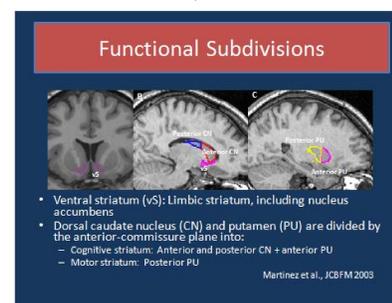

Behavioral Results

Slower responses when a high-value distractor is present indicate value-based distraction

PET Imaging

- **Scanner:** An HRRT PET scanner was used in three dimensional mode with a 2 mm axial resolution.

- **Timeframe:** Two 90-min scans, separated by 45 min.

- **Injection:** For each scan, 20 mCi of [11C]raclopride was administered intravenously as a bolus injection.

- **Motion Correction:** A thermoplastic mask was used to minimize head movement, and motion correction was conducted using a reconstruction-based algorithm[8].

- **ROI Definition:** The caudate nucleus, putamen, and ventral striatum were identified in each hemisphere as regions of interest (ROIs) via a structural MRI scan acquired prior to PET imaging[9]. The caudate and putamen were further divided in anterior and posterior portions via the anterior-commissure plane, resulting in 10 ROIs total.

Relating Individual Differences in Attentional Capture to the Release of Striatal Dopamine

To examine the relationship between attentional capture by previously reward-associated stimuli and striatal dopamine, we looked for correlations between our behavioral measure of value-based distraction (see behavioral results) and distractor-evoked dopamine release. Distractor-evoked dopamine release was defined as the difference in [11C]raclopride binding potential on distractor absent (D_{abs}) compared to distractor present (D_{pres}) scans, expressed as percent change: $[(D_{abs} - D_{pres})/D_{abs}]*100$

Right Posterior Caudate
$r = .755, p < .001$

Right Anterior Caudate
$r = .679, p = .001$

Right Posterior Putamen
$r = .630, p = .004$

Value-based distraction was predicted by the change in endogenous dopamine levels attributable to the processing of the distractors within three areas of the dorsal striatum (Bonferroni corrected for multiple comparisons).
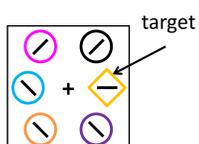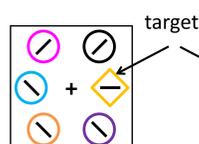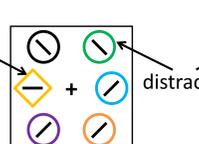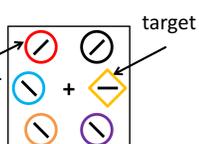
Conclusions

- Striatal dopamine signals contribute to the (value-based) control of attention

- Individual susceptibility to value-based distraction, which is associated with addiction[10], is mediated by the striatal dopamine system

- Automatic attentional orienting may be an important early-stage component of more elaborate habitual behavior and drug craving, which are also associated with dopamine release within the dorsal striatum[5-7]

References:
1. Anderson, B.A., Laurent, P.A., Yantis, S. (2011). PNAS, 108, 10367-10371.
2. Anderson, B.A. (2013). J Vis, 13(3), 1-16.
3. Anderson, B.A., Laurent, P.A., Yantis, S. (2014). Brain Res, 1587, 88-96.
4. Krebs, R.M., et al. (2012). Cereb Cortex, 22, 607-615.
5. Graybiel, A.M. (2008). Annu Rev Neurosci, 31, 359-387.
6. Volkow, N.D., et al. (2006). J Neurosci, 26, 6583-6588.
7. Wong, D.F., et al. (2006). Neuropsychopharmacology, 31, 2716-2727.
8. Mohy-ud-Din, H., et al. (2012). IEEE Nucl Sci Symp Conf Rec (2012), 3067-3078.
9. Oswald, L.M., et al. (2005). Neuropsychopharmacology, 30, 821-832.
10. Anderson, B.A., et al. (2013). Exp Clin Psychopharmacol, 21, 499-506.