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Nucleus accumbens activation mediates the influence of reward cues on financial risk-taking

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Abstract

In functional magnetic resonance imaging (FMRI) research, nucleus accumbens (NAcc) activation spontaneously increases prior to financial risk taking. Since anticipation of diverse rewards can increase NAcc activation, even incidental reward cues may influence financial risk-taking. Using event-related FMRI, we predicted and found that anticipation of viewing rewarding stimuli (erotic pictures for 15 heterosexual males) increased financial risk taking, and that this effect was partially mediated by increases in NAcc activation. These results are consistent with the notion that incidental reward cues influence financial risk taking by altering anticipatory affect, and so identify a neuropsychological mechanism that may underlie effective emotional appeals in financial, marketing, and political domains.

Keywords: accumbens, striatum, reward, cue, financial, risk, decision, FMRI, human

Introduction

Recent research suggests that affect changes during anticipation of, as well as in response to, goal outcomes [1-3]. Functionally, "anticipatory affect" might promote goal-directed behavior. However, anticipatory might also subvert goal-directed behavior when elicited by incidental stimuli. Here, we examined whether incidentally elicited anticipatory affect influences financial risk taking, and characterized neuropsychological correlates of this influence.

Event-related FMRI research has implicated activation of the nucleus accumbens (NAcc) as a neural marker of positive arousal (PA; feelings like "excitement"), since anticipation of both financial [2,4] and nonmonetary rewards (e.g., erotic pictures) [5,6] increases NAcc activation. Conversely, activation of the insula has been implicated as a neural marker of negative arousal (NA; feelings like "anxiety"), since anticipation of both financial [7] and nonmonetary punishments (e.g., pictures of snakes and spiders) [8] increases insular activation. Currently, however, it is not clear whether insular activation specifically marks NA or general arousal [9].

Anticipatory affect might influence financial risk taking by modifying the salience of potential gains or losses. In finance, risk (or variance in outcomes) increases proportional to the magnitude of anticipated gains and losses [10]. All other inputs being equal (e.g., information and incentives), PA should increase the salience of potential gains, and thus increase subsequent risk taking, while NA should increase the salience of potential losses,

and thus decrease subsequent risk taking. Indeed, in an investment task, endogenous NAcc activation predicted shifts to high risk options, whereas insular activation predicted shifts to low risk options [7]. Anticipatory affect should influence risk-taking independent of its source, and particularly when circumstances are uncertain or strategies are changing (i.e., people decide to change rather than repeat a past choice) [7].

This study explored the influence of positive stimuli on financial risk taking by examining whether: (1) incidental positive stimuli would increase shifts to a high risk option; (2) NAcc activation would increase prior to shifts to a high risk option; and (3) NAcc activation would mediate the influence of incidental positive stimuli on subsequent high risk shifts.

Methods

Subjects: Fifteen healthy right-handed (self-reported) heterosexual males (age mean=20.73; SD=2.12; range 18-26) participated. Along with typical magnetic resonance exclusions (e.g., metal in the body), subjects were screened for psychotropic drugs and ibuprofen, substance abuse in the past month, and history of psychiatric disorders (DSM IV Axis I) and gave informed consent. Subjects received $20.00 per hour for participating as well as a $10.00 cash endowment plus their earnings (positive or negative) from gambling during the task.

Task: Subjects played a practice version of the task prior to entering the scanner, during which they learned the associations between shapes and pictures (on which they were

explicitly tested), and were instructed that these stimuli were unrelated to the outcomes of subsequent gambles. To cleanly isolate within-subject shifts in financial risk taking, gambles featured equal expected value (i.e., $0.00, since each involved potential gains or losses) but different outcome variances (i.e., 50% probability of gaining or losing either $1.00 or $0.10; Figure 1).

During functional scanning, the task included 54 trials total (i.e., 18 positive, neutral, and negative). During the first part of each trial, subjects saw visual stimuli. These consisted of one of three shape cues (i.e., circle, square, or triangle; 4 sec) signaling the impending display of a positive (i.e., erotic couples), negative (i.e., snakes or spiders), or neutral (i.e., household appliances) picture, respectively (2 sec). The cue/picture stimulus combination was designed to maximize anticipatory affect, and subjects were asked to indicate the appearance of each picture with a button press. During the second part of each trial, subjects gambled. First, they waited while viewing two empty boxes (2 sec), then chose either a high (1.00) or low (0.10) risk financial gamble (2 sec, randomly appearing in left vs. right boxes), and finally saw the outcome of their choice for that trial as well as their cumulative earnings (2 sec). After scanning, subjects rated their reactions to each picture on dimensions of valence and arousal (subsequently mean-deviated within subject and rotated 45 degrees to derive independent ratings of PA and NA for each picture, as described in [11]). Reaction time to picture appearance and the choice prompt was log-transformed prior to analysis.

FMRI acquisition and analysis. Images were acquired with a 1.5-T General Electric MRI scanner and a standard quadrature head coil. Twenty-four contiguous axial 4-mm-thick slices (in-plane resolution 3.75X3.75 mm) extended axially from the mid-pons to the top of the skull. Functional scans were acquired with a T2*-sensitive spiral in-/out-pulse sequence (TR=2 s, TE=40 ms, flip=90°) [12]. High-resolution structural scans for localization and coregistration of functional data were acquired with a T1-weighted spoiled grass sequence (TR=100 ms, TE=7 ms, flip=90°). Analyses utilized AFNI software [13]. For preprocessing, data were sinc interpolated, concatenated across runs, motion-corrected, spatially smoothed (FWHM=4 mm), high-pass filtered (>.01 Hz), and normalized to percent signal change relative to the task voxel mean.

Localization analyses utilized multiple regression in which regressors of interest contrasted: (1) positive versus negative stimuli (i.e., cue + picture combined, which controls for arousal); (2) anticipation of choosing the high versus low risk option (anticipation); (3) anticipation of shifting to the high versus low risk option (anticipation); and (4) high risk gain versus loss outcomes (outcome; Figure 1). These were orthogonalized and convolved with a gamma-variate model of the hemodynamic response function prior to entry in the model [14]. Regressors of noninterest indexed choice reaction time, residual motion (six parameters), and baseline, linear, and quadratic trends. Regressor of interest coefficient maps were coregistered with structural maps, spatially normalized, and submitted to a one-sample t-test to test for random effects (a priori NAcc volumes of interest (VOIs) $p<.01$ uncorrected; cluster=3 4 mm^3 voxels).

Prediction analyses utilized VOI percent signal change timecourse peaks (from 8 mm diameter spherical VOIs identified in prior studies) to predict choice and shifts [7,15,16]. Logistic regressions analyzed whether NAcc (TC: +/-12,10,-2) and right insula (TC: 39,20,10) activation during choice anticipation (lagged by 4 sec) predicted subsequent decisions to choose or shift to the high risk option, both before and after controlling for experimental (e.g., positive stimuli) and control variables (i.e., cumulative earnings, preceding outcome).

Mediation analyses utilized VOI data from prediction analyses [17]. For the independent variable, positive stimuli were assigned a weight of 1, negative stimuli a weight of -1, and neutral stimuli a weight of 0. For the dependent variable, high risk shifts were assigned a weight of 1, and low risk shifts were assigned a weight of -1. Covariates included effects of cumulative earnings, winning on the previous trial, and right insula activation. The mediator was peak NAcc activation during choice anticipation (4 sec lag). To verify mediation, path significance was assessed using directional hypotheses ($p<.05$, one-tailed).

Results.

Behavioral analyses indicated that positive stimuli increased self-reported positive arousal (1.97±0.205) and negative stimuli increased self-reported negative arousal (1.32±0.153), relative to neutral stimulus-induced positive arousal (-1.42±0.138) and negative arousal (-1.39±0.139, $ps<.001$). Positive stimuli also increased subsequent high risk choices and shifts to the high risk option (67.8±3.84% and 61.9±3.19%), but negative

stimuli did not (59.3±3.97% and 42.7±4.38%), relative to neutral stimuli (57.40±4.26% and 39.1±4.77%; ps<.01). Log-transformed mean reaction time to pictures did not differ as a function of stimulus type (i.e., positive, negative, neutral). Log-transformed mean reaction time to the choice prompt did not differ as a function of prior stimulus type (as above) or choice type (i.e., high versus low risk, shift versus stay).

Localization analyses using multiple regression indicated that brain activation correlated with viewing positive versus negative stimuli in a number of regions including mesial prefrontal cortical and ventral striatal subcortical regions (e.g., NAcc, putamen) and posterior cingulate regions, as predicted. Anticipation of shifting to the high risk option versus shifting to the low risk option correlated with activation in the bilateral NAcc and caudate as well as deactivation of the right anterior insula, as predicted [7]. Conjunction of these contrasts yielded only NAcc activation (Figure 2). Replicating previous findings [15], gain versus loss high risk outcomes correlated with activation in the MPFC, caudate, putamen and posterior cingulate (Table 1).

Prediction analyses utilized logistic regressions to determine whether brain activation could predict financial risk taking. The first analysis indicated that viewing positive stimuli predicted subsequent shifts to the high risk option, but gains on prior high risk trials predicted shifts to the low risk option. A second analysis indicated that bilateral NAcc activation significantly predicted subsequent shifts to the high risk option. A third analysis including stimulus and brain activation variables together indicated that viewing positive stimuli no longer significantly predicted shifts to the high risk option, but NAcc

activation did, suggesting a critical role for NAcc activation (Table 2). The Akaike Information Criterion (AIC) indicated that the increased fit of this model was not solely due to increased parameters. Analyses including all choices (rather than just shifts) revealed a similar but less robust pattern of results, as predicted.

Mediation analyses evaluated the directional prediction that NAcc activation might mediate the influence of positive stimuli on shifts to the high risk option. Bootstrapped mediation revealed significant paths from positive stimuli to NAcc activation and from NAcc activation to shifts to the high risk option. The direct path from positive stimuli to shifts to the high risk option was also significant, but less so after controlling for indirect paths incorporating NAcc activation (Figure 3). The NAcc was the only region examined whose activation both predicted shifting to the high risk option and also mediated the influence of positive stimuli on high risk shifts.

Previous analyses controlled for individual differences by incorporating fixed effects into models. However, an anticipatory affect account further predicts that individuals who experience greater self-reported positive arousal in response to positive stimuli should make more shifts to the high risk option. The correlation between individual mean self-reported positive arousal to the positive stimuli and proportion of high risk to total shifts was significant ($r=0.70$, $p<.01$), while the correlation of mean self-reported negative arousal to the positive stimuli and proportion of low risk to total shifts was not.

Discussion.

This study investigated whether incidental reward cues can influence financial risk taking and sought to identify underlying neural mechanisms. Positive stimuli increased shifting to a high risk option, and this behavioral influence was partially mediated by NAcc activation. Further, individual differences in self-reported positive arousal in response to positive stimuli predicted the strength of these effects. Together, these results suggest that even incidental reward cues can act on anticipatory affect to alter financial risk taking. The findings have broad implications for understanding how affect might influence decisions, and for assessing the effectiveness of emotional persuasive techniques.

The findings provide an initial demonstration that incidental external stimuli can influence subsequent financial risk taking, and that brain activation in a specific region mediates this behavioral effect. Other studies have correlated spontaneous (or endogenous) activation in related brain regions with subsequent decisions. These experiments have focused on investing [7], learning [18], or gambling [19,20] tasks, in which prior feedback could potentially provide domain-specific information about the next best choice. In this study, however, affective stimuli had no explicit or implicit relationship to subsequent gambles, and so could not inform the next choice. Still, positive stimuli influenced subsequent choice, and did so partially as a function of NAcc activation. Combined with earlier demonstrations that NAcc activation correlates with stimulus-elicited positive arousal, this evidence is consistent with the notion that anticipatory affect has the capacity not only to facilitate, but also to subvert decisions.

Importantly, a conjunction analysis indicated that only the NAcc was activated both by positive stimuli and by anticipation of shifting to the high risk option. NAcc activation does not increase solely in response to reward cues, since spontaneous changes in NAcc activation predicted risky shifts in an earlier study [7]. The findings also could not be accounted for in terms of motor preparation, because peak activation was modeled during anticipation, when subjects saw two boxes and knew that the high risk option would appear in one and the low risk option in the other but did not know which option would appear in which box (also, reaction time did not differ between high and low risk choices or shifts). A "switching" account predicts that NAcc activation should increase prior to shifting from a repeated choice to any new choice [21], but not that NAcc activation should preferentially increase prior to shifts to the high risk but not the low risk option.

Conclusion.

Incidental reward cues can influence financial risk taking, and may do so in part by activating the NAcc. From a financial standpoint, these results imply that anticipatory affect may alter the perception of rewards, and the tendency to weigh them against risks [7,22]. Thus, these findings may lead to methods of determining when persuasive appeals should and should not work -- whether they appeal to passion or to reason.

References

1. Loewenstein GF, Weber EU, Hsee CK, Welch N. Risk as feelings. **Psychological Bulletin** 2001; 2:267-286.
2. Knutson B, Adams CM, Fong GW, Hommer D. Anticipation of increasing monetary reward selectively recruits nucleus accumbens. **Journal of Neuroscience** 2001; 21:RC159.
3. Bechara A, Tranel D, Damasio H, Damasio AR. Failure to respond autonomically to anticipated future outcomes following damage to prefrontal cortex. **Cerebral Cortex** 1996; 6:215-225.
4. Preuschoff K, Bossaerts P, Quartz SR. Neural differentiation of expected reward and risk in human subcortical structures. **Neuron** 2006; 51:381-390.
5. Hamann S, Herman RA, Nolan CL, Wallen K. Men and women differ in amygdala response to visual sexual stimuli. **Nature Neuroscience** 2004; 7:411-416.
6. Sabatinelli D, Bradley MM, Lang PJ, Costa VD, Versace R. Pleasure rather than salience activates human nucleus accumbens. **Journal of Neurophysiology** 2007; 98:1374-1379.
7. Kuhnen CM, Knutson B. The neural basis of financial risk-taking. **Neuron** 2005; 47:763-770.
8. Nitschke JB, Sarinopoulos I, Mackiewicz KL, Schaefer HS, Davidson RJ. Functional anatomy of aversion and its anticipation. **NeuroImage** 2006; 29:106-116.
9. Wager TD, Phan KL, Liberzon I, Taylor SF. Valence, gender, and lateralization of functional brain anatomy in emotion: A meta-analysis of findings from neuroimaging. **NeuroImage** 2003; 19:513-531.
10. Markowitz H. Portfolio selection. **The Journal of Finance** 1952; 7:77-91.
11. Knutson B, Taylor J, Kaufman M, Peterson R, Glover G. Distributed neural representation of expected value. **Journal of Neuroscience** 2005; 25:4806-4812.
12. Glover GH, Law CS. Spiral-in/out BOLD fMRI for increased SNR and reduced susceptibility artifacts. **Magnetic Resonance in Medicine** 2001; 46:515-522.
13. Cox RW. AFNI: Software for analysis and visualization of functional magnetic resonance images. **Computers in Biomedical Research** 1996; 29:162-173.
14. Zarahn E. Testing for neural responses during temporal components of trials with BOLD fMRI. **NeuroImage** 2000; 11:783-796.
15. Knutson B, Fong GW, Bennett SM, Adams CM, Hommer D. A region of mesial prefrontal cortex tracks monetarily rewarding outcomes: Characterization with rapid event-related FMRI. **NeuroImage** 2003; 18:263-272.
16. Knutson B, Rick S, Wimmer GE, Prelec D, Loewenstein G. Neural predictors of purchases. **Neuron** 2007; 53:147-156.
17. Preacher KJ, Hayes AF. SPSS and SAS procedures for estimating indirect effects in simple mediation models. **Behavior Research Methods, Instruments, & Computers** 2004; 36:717-731.

18. Hampton AN, O'Doherty JP. Decoding the neural substrates of reward-related decision making with functional MRI. **Proceedings of the National Academy of Science** 2007; 104:1377-1382.
19. Cohen MX, Ranganath C. Behavioral and neural predictors of upcoming decisions. **Cognitive, Affective, and Behavioral Neuroscience** 2005; 5:117-126.
20. Matthews SC, Simmons AN, Lane SD, Paulus MP. Selective activation of the nucleus accumbens during risk-taking decision making. **NeuroReport** 2004; 15:2123-2127.
21. Robbins TW, Everitt BJ. Neurobehavioral mechanisms of reward and motivation. **Current Opinion in Neurobiology** 1996; 6:228-236.
22. Knutson B, Bossaerts P. Neural antecedents of financial decisions. **Journal of Neuroscience** 2007; 27:8174-8177.

Table 1. Brain activation correlated with exposure to positive versus negative stimuli (i.e., cue+picture), during anticipation of switching to a high versus low risk option, and in response to gain versus loss high risk outcomes. (*=predicted region significant at p<.005 corrected, cluster > two 4 mm^3 voxels; other regions significant at p<.001 uncorrected, cluster > two 4 mm^3 voxels).

Positive > Negative Stimuli	**Peak Z**	**R**	**A**	**S**
L Subgenual Cingulate	4.09	-8	38	-11
R Subgenual Cingulate	3.86	11	23	-11
L OFC	3.91	-26	19	-11
L Caudate Head	3.97	-4	15	1
L NAcc*	3.09	-12	11	-4
R NAcc*	3.22	7	8	-6
R Putamen	3.89	19	8	-6
R Middle Frontal Gyrus, BA 6	4.10	33	0	42
R Middle Frontal Gyrus, BA 9	4.34	49	4	38
L Middle Temporal Gyrus	3.96	-56	-56	8
L Middle Temporal Gyrus	4.42	-49	-53	4
L Posterior Cingulate	3.89	-4	-56	16
R Middle Temporal Gyrus	4.09	38	-60	19
L Middle Occipital Gyrus	3.94	-42	-83	16
High > Low Risk Shift				
R Anterior Insula**	-2.38	33	22	11
L Caudate*	3.44	-8	22	0
R Caudate*	3.79	4	12	4
L NAcc*	3.29	-12	4	-6
R NAcc*	3.45	12	6	-6
Gain vs Loss Outcome				
MPFC*	3.34	0	62	5
L Caudate*	3.52	-15	12	8
R Putamen*	3.65	18	8	-3
L Putamen*	3.38	-18	8	-3
R Inferior Frontal Gyrus	3.73	45	8	27
L Precentral Gyrus	3.73	-56	0	4
Posterior Cingulate*	3.55	0	-53	15
R Lingual Gyrus	3.74	22	-75	-6

Table 2. Logistic regressions predicting shifts in the cued risk task (n=15)

	Stimulus	Brain	Combined
Constant	0.97 0.98 (1.010)	1.47 1.50 (1.02)	1.42 1.46 (1.029)
Cumulative earnings	0.11 0.01 (0.075)	0.25 0.02 (0.075)	0.05 0.00 (0.075)
Preceding outcome	-7.40*** -2.01 (0.271)	-7.75*** -2.19 (0.283)	-7.54*** -2.14 (0.284)
Positive stimulus	2.00* 0.57 (0.283)		1.75 0.50 (0.286)
NAcc (bilateral)		2.74*** 1.14 (0.416)	2.59** 1.09 (0.419)
Insula (right)		-1.15 -0.44 (0.378)	-1.03 -0.39 (0.378)
Number of obs.	315	315	315
Pseudo-R^2	0.169	0.178	0.186
AIC	398.6	396.3	395.3

Notes: Regressions included subject fixed effects. However, no subjects were significant at p<.01 and omission of fixed effects did not affect the results.
Significance: *<.05; **<.01; ***<.001, two-tailed.

Figure 1. Cued risk task structure and regressor timing. Subjects first viewed affective stimuli consisting of a shape (cue: circle, triangle, square) followed by a picture (picture: erotic couples, household appliances, snakes and spiders). Next, subjects gambled by first waiting (anticipation), next choosing the high or low risk option (choice), and finally viewing the outcome of their choice (outcome). Conjoined regressors modeled brain activation in response to affective stimuli (cue + picture) and during anticipation of choosing the gamble (anticipation).

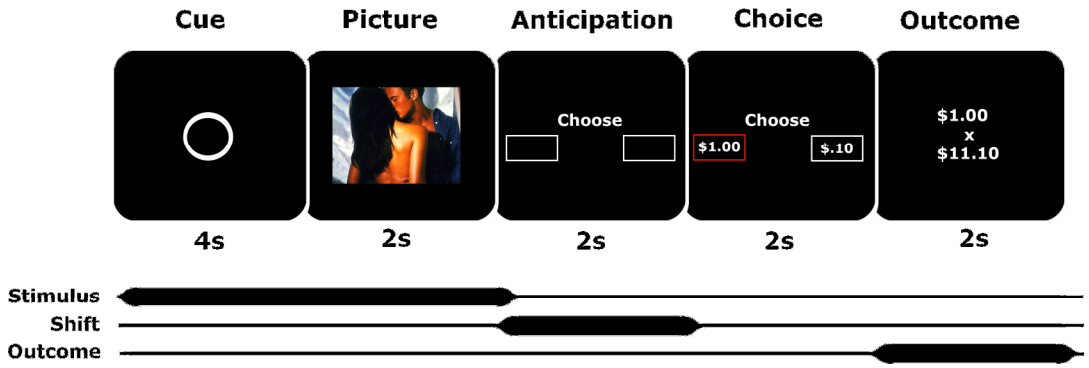

Figure 2. Brain activation associated with viewing positive vs. negative stimuli (left), with anticipation of shifting to the high risk option versus shifting to the low risk option (middle), and with their conjunction (right; p<.01, two-tailed, uncorrected).

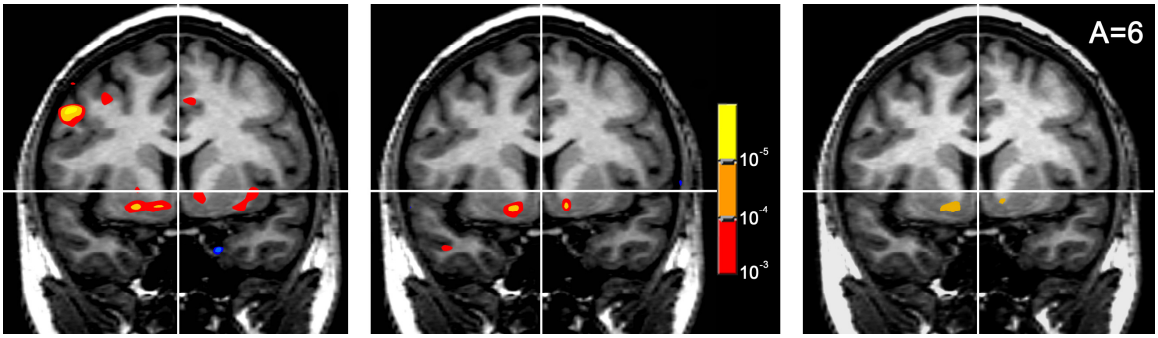

Figure 3. Anticipatory NAcc activation partially mediates the influence of positive stimuli on subsequent shifts to the high risk option (t-scores above paths, *p<.025, †p<.05; one-tailed). Bootstrapped (robust; n=1000) mediation analysis indicated a significant path from positive stimuli to NAcc activation (beta=0.037, SEM=.022; t(315)=1.69, p<.05, one-tailed) and a significant path from NAcc activation to high risk shifts (beta=0.411, SEM=.162; t(315)=2.54, p<.05, one-tailed). The path from positive stimuli to high risk shifts was also significant (beta=0.137, SEM=.063; t(315)=2.16, p<.05, one-tailed), but less so (beta=0.121, SEM=.063; t(315)=1.93, p<.05, one-tailed) after adding indirect paths involving NAcc activation to the model. Bias corrected and accelerated confidence intervals verified the significance of this partial mediation (CI bounds=.0002 to .0447). Of the model covariates (i.e., cumulative earnings, anterior insula activation), only losses on the previous trial (t(315)=-9.14, p<.001) significantly predicted shifts to the high risk option.