Ventromedial prefrontal cortex activation is critical for preference judgments

Martin P. Paulus[1,2,3,CA] and Lawrence R. Frank[3,4]

[1]Laboratory of Biological Dynamics and Theoretical Medicine; [2]Departments of Psychiatry and [4]Radiology University of California San Diego, La Jolla, CA 92093-0603; [3]Veterans Affairs San Diego Health Care System, CA, USA

[CA]Corresponding Author: martin@mag.ucsd.edu

Received 24 February 2003; accepted 28 March 2003

DOI: 10.1097/01.wnr.0000078543.07662.02

Preference judgment, the process of selecting a response from several alternatives based on which alternative the subject likes best, is an important aspect of daily life. The current study examined whether neural substrates that are thought to be critical for generating somatic markers are involved in preference judgments. Fifteen healthy, right-handed subjects performed a preference judgment task during functional magnetic resonance imaging. The medial frontal gyrus was significantly more activated during the preference judgment trials, relative to visual discrimination trials. Other areas that were also differentially activated included the posterior parietal cortex, the anterior cingulate and the left anterior insula. These findings are consistent with the role of the ventromedial prefrontal cortex in the representation of complex appetitive states. *NeuroReport* 14:1311–1315 © 2003 Lippincott Williams & Wilkins.

Key words: Decision-making; Functional magnetic resonance imaging (fMRI); Preference judgments

INTRODUCTION

Judgment and decision-making are complex processes that involve both rational and emotional functions. These processes may be based on logical reasoning, heuristics (rule-based response selection), rewards, or punishments associated with the outcome. One important component in judgment and decision-making situations is the evaluation of preferences, i.e. liking or disliking the available alternatives. A preference judgment is the process of selecting a response among several alternatives based on which alternative the subject likes best.

The psychology of decision-making has revealed that preference judgments, when associated with probabilities and monetary outcomes, are frequently not rational but show a number of systematic biases (for review see [1]). Preference judgments occur in many daily situations and form the basis of personality assessments that are used to establish individual differences [2]. Moreover, preference judgments may have important implications for subjects with neuropsychiatric disorders [3]. For example, preference judgments may lead to experimenting with drugs of abuse and may constitute the first step to abuse liability. Although preference judgments play a critical role in our everyday life, their neural basis is not well understood, nevertheless, several studies have provided important clues. In a primary reward paradigm, preference judgments were associated with activation in somatosensory cortex [4]. Experimentally, previous exposure to the stimuli has been shown to enhance the preference for the stimulus on subsequent trials [5]. Activation of medial prefrontal cortex has been reported when subjects are asked to select between two abstract stimuli, when some of these stimuli were presented subliminally on previous trials [6].

The somatic marker hypothesis proposed by Damasio and colleagues [7] posits that external or internal stimuli initiate a state that is associated with pleasurable or aversive somatic markers. These markers function to guide the person's behavior by biasing the selection towards actions that result in an increase in pleasurable somatic markers, while avoiding actions resulting in aversive somatic markers. The current study was conducted to examine whether the neural substrates that are thought to be critical for generating somatic markers are involved in preference judgments. Specifically, it was hypothesized that, if the ventromedial prefrontal cortex is important for processing of reward expectations, this structure should selectively activate when subjects are asked to make a preference judgment versus a visual discrimination judgment. Support for this hypothesis would further confirm that somatic markers, as processed in the ventromedial prefrontal cortex, are critical for decision-making processes even when there is no immediate advantageous or disadvantageous outcome associated with the response alternatives. Therefore, unconscious hunches [8] instead of explicit rational decision-making may be fundamental for preference judgments.

MATERIALS AND METHODS

Subjects: Fifteen healthy, right-handed subjects (six females and nine males) age 41.3 ± 2.2 years (range 27–56) with an average education level of 15.2 ± 0.5 years (range 12–18) without a life-time history of Axis I DSM IV disorders based on a structured clinical interview for DSM IV diagnosis [9] participated in this study, which was approved by the UCSD Human Research Protection Program. Handedness was determined by a series of questions about hand use during daily activities. These subjects gave informed, written consent and performed a preference judgment task within an MRI scanner during an fMRI scanning protocol.

Task: There were three trial types: 20 preference judgment trials, 20 visual discrimination trials, and 24 null trials. Each trial lasted 8 s. For the preference judgment trial, shown in Fig. 1, two pictures of soft drinks (obtained from internet advertisements) and an instruction were shown with a SOA of 500 ms. The subjects were asked to select the preferred option by pressing a left or right mouse button. After

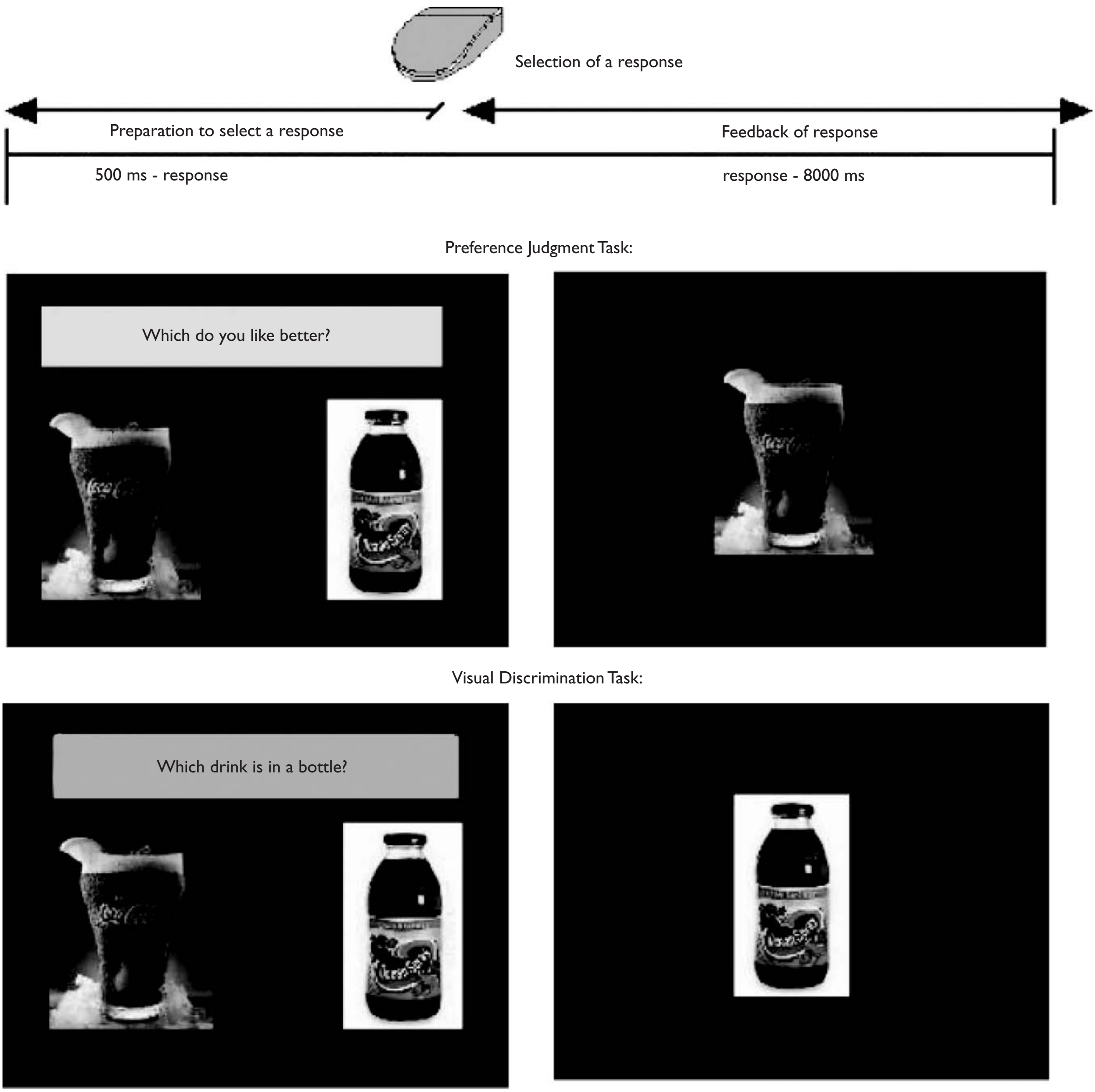

Fig. 1. Preference Judgment Task and Visual Discrimination Task for the fMRI experiment. A fixation cross was displayed from 0 to 500 ms.

Table 1. Center of mass for volume-thresholded clusters and their F-statistics.

Volume (μl)	x	y	z	F(1,14)	R/L	Description
4736	27	−78	41	10.87	R	Precuneus
2560	−9	50	4	12.95	R/L	Medial frontal gyrus
1792	21	−68	58	8.09	R	Superior parietal lobule
1408	−39	−18	17	6.24	L	Insula
1344	14	40	1	14.2	R	Anterior cingulate

making a selection, the subjects saw the selected picture for the remainder of the trial. For the visual discrimination trial, subjects saw the same picture set that was used for the preference judgment trials; however, they were asked to identify which soft drink was in a bottle, a can, or a carton. Interspersed between the judgment trial type and the visual discrimination trial type were fixation cross trials.

Behavioral measures: The behavioral response was obtained from the button press and recorded by the PC computer during each trial and was used to determine response latency, i.e. the duration from presentation of the stimulus to selecting a response and the number of correct discrimination judgments.

fMRI: During the preference judgment task an fMRI run sensitive to blood oxygenation level-dependent (BOLD) contrast was collected for each subject using a 1.5 T Siemens (Erlangen, Germany) scanner (T2* weighted echo planar imaging, TR = 2000 ms, TE = 40 ms, 64 × 64 matrix, 204 mm axial slices, 256 scans). fMRI acquisitions were time-locked to the onset of each trial. During the same experimental session, a high resolution T1-weighted image (MPRAGE, TR = 11.4 ms, TE = 4.4 ms, flip angle = 10°, FOV = 256 × 256, 1 mm^3 voxels) was obtained for anatomical reference. For preprocessing, voxel time series were interpolated to correct for non-simultaneous slice acquisition within each volume and corrected for 3D motion. The stimulus paradigm was a randomized fast-event related design with 24 null trials interspersed between the 20 preference judgment and 20 visual discrimination trials.

fMRI analysis pathway: The data were preprocessed and analyzed with the software AFNI [10]. The preprocessed time series data for each individual was analyzed using a multiple regression model consisting of seven regressors. Two regressors were used for the preference judgment and the visual discrimination task, respectively. These regressors were convolved with a gamma variate function modeling a prototypical hemodynamic response prior to inclusion in the regression model. In addition three regressors were used to account for residual motion (in the roll, pitch, and yaw direction). Regressors for baseline and linear trends were used to eliminate slow signal drifts. The AFNI program 3dDeconvolve was used to calculate the estimated voxel-wise response amplitude. A Gaussian filter with FWHM 6 mm was applied to the voxel-wise percent signal change data to account for individual variations of the anatomical landmarks. Data of each subject were normalized to Talairach coordinates.

Statistical analyses: The voxel-wise percent signal change data were entered into a mixed model ANOVA with response type as a fixed factor and subjects as a random factor. A threshold adjustment method based on Monte-Carlo simulations was used, which determined that a voxel-wise *a priori* probability of 0.05 would result in a corrected cluster-wise activation probability of 0.05 if a minimum volume of 1024 μl and a connectivity radius of 4.0 mm was considered. All analyses for the behavioral data were carried out with SPSS 10.0 [11]. A mixed model ANOVA (fixed factor: task conditions, random factor: subjects) was used to analyze the behavioral measures.

RESULTS

Behavioral results: Subjects correctly responded on 90% of the visual discrimination trials. Subjects took longer to select a response during preference judgment trials (3298 ± 179 ms) relative to the visual discrimination trials (2869 ± 158 ms; $F(1,14) = 24.6$, $p < 0.01$). These differences in latencies between the judgment and the visual discrimination trials were not correlated with age (r = 0.29, NS) or education (r = 0.065, NS).

Functional neuroimaging results: Bilateral ventromedial prefrontal cortex (medial frontal gyrus) showed significantly more activation during the preference judgments trials relative to the visual discrimination trials (Table 1, Fig. 2). The degree of activation in this area during the preference judgment was not correlated with the latency to select a response (during the judgment trials, r = 0.29, NS, or visual discrimination trials, r = 0.10, NS) or with the number of visual discrimination errors (r = 0.05, NS). Other areas that showed significant activation differences between the preference task and the visual discrimination task included right posterior parietal cortex (precuneus), anterior cingulate and left anterior insula. The activation in the anterior cingulate during the discrimination task was significantly correlated with the number of discrimination errors (r = 0.54, $p < 0.05$).

DISCUSSION

The main finding of this investigation is the fact that the medial frontal gyrus, as part of the ventromedial prefrontal cortex, plays a critical role in preference judgments, an important component process of decision making. Other areas that were also differentially activated included the posterior parietal cortex, the anterior cingulate and the left anterior insula. In combination, these findings are consistent with the role of the ventromedial prefrontal cortex in the representation of complex appetitive states.

Several processes have been proposed to take place during preference judgments. Some investigators have argued that due to limited processing capacity, subjects often do not have well-defined existing preferences, but construct them using a variety of strategies contingent on task demands [12,13]. Others have suggested that subjects preference judgments result from a competition between hedonic and utilitarian aspects of each choice alternative [14], competition between subjective emotional states such as desire and willpower [15], the selection of a specific

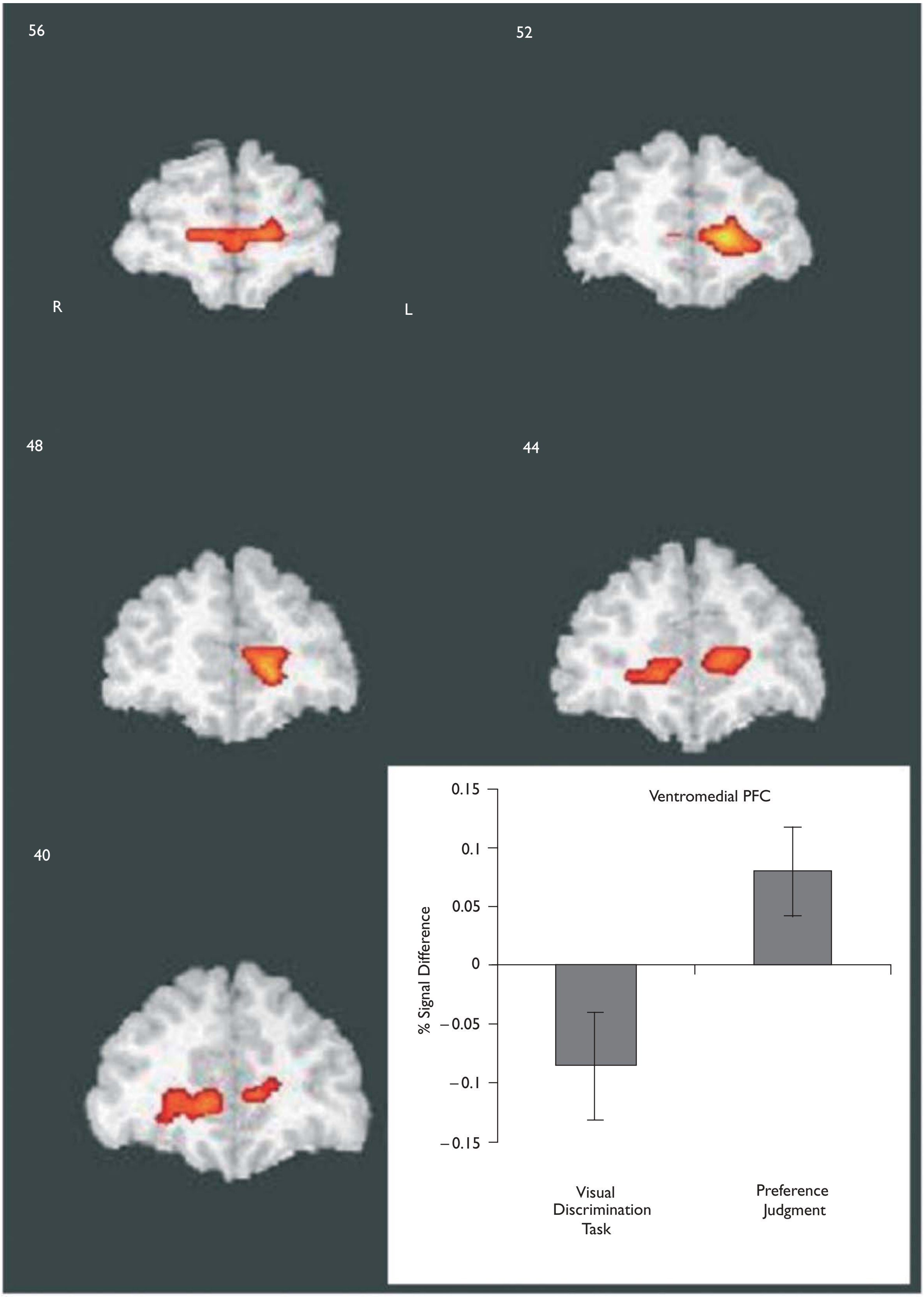

Fig. 2. Task-related activation during preference judgment task relative to visual discrimination task in medial prefrontal cortex, numbers indicate Talairach y coordinate. Inset: ventromedial prefrontal cortex activates more when subjects make preference judgments relative to making the visual discrimination task.

dimension that enhances the contrast between the alternatives [16], or habit-based processing [17]. Subjects are thought to use a single dimension, such as how risky or safe a response option is, when making preference judgments across task domains [18]. Finally, the reward magnitude ratios of the competing alternatives are hypothesized to determine the frequency of selecting an alternative during preference judgments [19].

The current study is consistent with the idea that preference judgment may be based on complex somatic states that are difficult to verbalize but have a powerful influence on which response is liked best [8]. The somatic marker hypothesis of Damasio provides a coherent theory for the complex process of decision making and is based on the notion that the brain generates somatic states that are associated with a potential response alternative. The degree to which somatic states associated with each action alternative in a preference judgment situation is appetitive or aversive, which ultimately determines the preference of one alternative over another. In the context of the somatic marker hypothesis, our finding of activation of both ventromedial prefrontal cortex and anterior insula may correspond to the competitive influences of appetitive (what is liked) versus aversive (what is disliked) when making the preference judgment.

Functional neuroimaging studies have shown insula related activation during the processing of fearful [20] or disgusted [21] faces, during the anticipation of electric shocks [22], and during script-induced sad mood induction [23]. Recent evidence suggests that the insula is involved in processing not only disgust [24] and that structures involved in emotion processing may be active during both positive and negative emotions [25].

In conclusion, competition between appetitive and aversive representations of somatic markers may be the crucial components that underlie preference judgments in the brain. These states may be based on prior experiences, external influences, or self-generated thoughts. Preference judgments are ubiquitous and are important for many domains of life. Therefore, elucidating the neurobiology underlying preference judgments may have help to understand how humans select what they like.

REFERENCES

1. Birnbaum MH. *Org Behav Hum Decision Proc* **52**, 319–330 (1992).
2. Costa PT and McCrae RR. *Psychol Assess* **4**, 5–13 (1992).
3. Petry NM, Bickel WK and Arnett M. *Addiction* **93**, 729–738 (1998).
4. Berns GS, McClure SM, Pagnoni G *et al. J Neurosci* **21**, 2793–2798 (2001).
5. Zajonc RB, Crandall R and Kail RV Jr. *Percept Mot Skills* **38**, 667–678 (1974).
6. Elliott R and Dolan RJ. *J Neurosci* **18**, 4697–4704 (1998).
7. Damasio AR, Damasio H and Christen Y. *Neurobiology of Decision-making*. Berlin: Springer; 1996.
8. Bechara A, Damasio H, Tranel D *et al. Science* **275**, 1293–1295 (1997).
9. Spitzer RL, Williams JB, Gibbon M *et al. Arch Gen Psychiatry* **49**, 624–629 (1992).
10. Cox RW. *Computers Biomed Res* **29**, 162–173 (1996).
11. Norusis MJ. *SPSS Base System User's Guide*. Chicago: SPSS Inc.; 1990.
12. Slovic P. *Am Psychol* **50**, 364–371 (1995).
13. Bettman JR, Luce MF and Payne JW. *J Consumer Res* **25**, 187–217 (1998).
14. Dhar R and Wertenbroch K. *J Marketing Res* **37**, 60–71 (2000).
15. Hoch SJ and Loewenstein GF. *J Consumer Res* **17**, 492–507 (1991).
16. Mellers BA, Chang Sj, Birnbaum MH *et al. J Exp Psychol Hum Percept Perf* **18**, 347–361 (1992).
17. Lindbladh E and Lyttkens CH. *Soc Sci Med* **55**, 451–465 (2002).
18. Fiedler K, Knoess R, Luebke-Sure B *et al. J Exp Soc Psychol* **25**, 326–342 (1989).
19. Herrnstein RJ, Rachlin H and Laibson DI. The Matching Law: Papers in *Psychology and Economics*; 1997.
20. Morris JS, Friston KJ, Bèuchel C *et al. Brain* **121**, 47–57 (1998).
21. Phillips ML, Young AW, Scott SK *et al. Proc R Soc Lond B Biol Sci* **265**, 1809–1817 (1998).
22. Chua P, Krams M, Toni I *et al. Neuroimage* **9**, 563–571 (1999).
23. Liotti M, Mayberg HS, Brannan SK *et al. Biol Psychiatry* **48**, 30–42 (2000).
24. Schienle A, Stark R, Walter B *et al. Neuroreport* **13**, 2023–2026 (2002).
25. Aalto S, Naatanen P, Wallius E *et al. Neuroreport* **13**, 67–73 (2002).

Acknowledgement: We would like to acknowledge the invaluable help of Kelly Winternheimer and Thuy Le in conducting the experiments. This work was supported by a grant from NIMH (R21DA13186, MPP).