The Envious Brain: The Neural Basis of Social Comparison

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Abstract: Humans have a drive to evaluate themselves by examining their abilities and outcomes in comparison to others. The present study examined the emotional and neural correlates of upward social comparison (comparison with those who have more) and downward social comparison (comparison with those who have less). Two experiments were conducted with volunteers in an interactive game of chance, in which a putative player won or lost more money than the participant. The results showed that even when participants lost money, they expressed joy and schadenfreude (gloating) if the other player had lost more money. On the other hand when they actually won money, but the other player had won more they expressed envy. This pattern was also demonstrated in a differential BOLD response in the ventral striatum. Comparing the activations between an actual gain and a relative gain indicated that even when a person loses money, merely adding information about another person's greater loss may increase ventral striatum activations to a point where these activations are similar to those of an actual gain. We suggest that the ventral striatum plays a role in mediating the emotional consequences of social comparison. *Hum Brain Mapp 31:1741–1750, 2010.* © 2010 Wiley-Liss, Inc.

Key words: emotion; envy; fMRI; reward; schadenfreude

INTRODUCTION

Throughout the evolution of social behavior, it may have become essential for individuals to compare their own state and payoffs with those of others, possibly providing individuals with a selective advantage. Comparative behavior is not unique to humans. Even capuchin monkeys have been found to respond negatively when they are treated inequitably compared to a group mate [Brosnan and De Waal, 2003]. This self-other comparison and competitive behavior may be critical for various purposes, such as self evaluation [Festinger, 1954] and social cooperation [Brosnan et al., 2005]. Indeed, a large body of evidence concerning social comparison processes has emphasized that relative material payoffs affect people's emotional reactions [Adams, 1963; Fehr and Schmidt, 1999; Festinger, 1954; Homans, 1961; Stouffer, 1949].

The emotional reactions to the success or failure of others can vary greatly toward different people as well as toward the same person. When another person experiences failure or success, our emotional reaction can take various courses. It can range from feeling envious about the other's possessions, or feeling sympathy toward someone

Contract grant sponsor: Israeli Scientific Foundation (ISF); Contract grant number: 489/08.

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Received for publication 11 August 2009; Revised 1 November 2009; Accepted 17 November 2009

DOI: 10.1002/hbm.20972

Published online 4 March 2010 in Wiley Online Library (wileyonlinelibrary.com).

who just lost all his savings, to feeling pleasure at seeing an arrogant leader fall [Ben-Ze'ev, 2000]. These emotions, involving two-person situations in which one's emotion depends on the other's lot, are classified by some as fortune-of-others emotions [Ortony and Collins, 1988]. Envy is a negative reaction in the face of one's inferiority compared to another's good fortune. It is comprised of the wish to abolish inferiority by either having another person's possession or success and/or the wish that the other person did not possess the desired characteristic or object [Ben-Ze'ev, 2000; Parrott, 1991]. On the other hand, gloating or schadenfreude denotes one's joy about the shame or misfortune of another [Ben-Ze'ev, 1992, 2000; Smith et al., 1996].

It has been suggested that the role of rewards and punishments in emotions is crucial [Rolls, 2005]. Interestingly, recent neuroimaging studies demonstrate that the reward system of the brain is involved in situations concerning not just one's own, but also another's pain and gain [Delgado et al., 2008; Lieberman and Eisenberger, 2009; Zink et al., 2008]. Fliessbach et al. showed that comparison of payments affects the brain response in the ventral striatum. Specifically, receiving less money than another subject was associated with a reduced BOLD signal in the ventral striatum [Fliessbach et al., 2007]. Singer et al. reported increased activity in the ventral striatum in men in response to the pain experienced by an unfair player [Singer et al., 2006]. Furthermore, it was recently reported that the striatum is involved also in the acquisition of one's good reputation, suggesting that there is a "common neural currency" for social and monetary rewards [Izuma et al., 2008].

Neurons in the nonhuman primate striatum have been shown to respond to the anticipation [Apicella et al., 1992; Kawagoe et al., 1998] and the delivery [Apicella et al., 1991; Hikosaka et al., 1989] of rewards. Although numerous studies have suggested a major role of the ventral striatum in the human brain's "reward system" [Breiter et al., 2001; Lieberman and Eisenberger, 2009; O'Doherty et al., 2002] no study to date has examined the role of relative rewards and the ventral striatum in envy and schadenfreude. Therefore, the aim of the present study was to investigate the emotional and neural bases of comparative rewards.

Two experiments were conducted using a paradigm involving immediate monetary gains and losses, whereby participants either won more money or received less money than a putative player. Participants played the game with a fake participant who either won more money (envy manipulation) or lost more money (schadenfreude manipulation) than the participant. The goal of the first experiment was to examine whether upward social comparison (comparing ourselves with those who have more than us) provokes envy whereas downward social comparison provokes schadenfreude. The second experiment was conducted using fMRI to examine the role of the ventral striatum in downward and upwards social comparison. Although recent imaging studies have been increasingly capable of characterizing the role of the ventral striatum in relative reward [Fliessbach et al., 2007] and in envy and schadenfreude [Takahashi et al., 2009], no study to date have examined directly the emotional consequences of relative rewards. Additionally, it is still unknown if relative rewards are experienced in a similar manner as absolute rewards. Under the assumption that relative outcomes are as rewarding as absolute outcomes, we expected that the ventral striatum would respond similarly to absolute and relative gains and losses.

MATERIALS AND METHODS

Experiment 1—The Emotional Correlates of Relative Rewards

Subjects

Participants were 39 students (22 females and 17 males) ranging in age from 20 to 30 years (M = 24.45, SD = 2.91). Participants were recruited through advertisements placed at local universities. All participants were right-handed, Hebrew speaking and had a normal or corrected-to-normal visual acuity. After providing each participant with a description of the study, written consent was obtained and participants were told that they could withdraw at any time. Ethical approval was provided by the University of Haifa's Ethics Committee. One subject (male) who exhibited suspiciousness about the existence of the other player was excluded from the analysis, resulting in a final sample of 38 subjects.

Experimental setting and task

Following a simplified behavioral definition of fortune-of-others emotions, which relates to the disparities between one's and the other's gain or loss (relative rewards), a game-of-chance task was designed to directly provoke social comparison and its accompanying emotional outcomes (see Fig. 1). Based on previous reports assessing social comparison [Van Dijk et al., 2006], the gender of the putative player was matched to that of the participant.

The subjects were told that they would be simultaneously playing with another player in a game of chance involving color selection with immediate monetary gains and losses. During the game, participants were asked to choose one of three doors of different colors. Participants were told that this is a game of chance and that there is no correlation between the color or the location of the door and the sum of money they can win or lose. This was emphasized to prevent subjects from trying to look for rules that may affect their chances of gaining or losing money. Furthermore, they were told that the consequence of their decision will not have any effect on the

TABLE I. Multiple planned contrasts were conducted to examine the emotional consequences of relative loss vs. relative gain

	Relative Loss –Relative Gain	Relative Gain	Relative Loss
I currently feel joy	$P < 0.003$	M = 3.1646 SD = 1.19584	M = 2.6789 SD = 1.10720
I currently feel envy	$P < 0.003$	M = 1.8232 SD = 0.88431	M = 2.5549 SD = 1.19991
I currently feel schadenfreude	$P < 0.003$	M = 2.3049 SD = 1.23049	M = 1.4085 SD = 0.64356
I currently feel sadness	$P < 0.003$	M = 2.1890 SD = 1.13438	M = 2.6199 SD = 1.26629
I feel less good when I compare myself to the other	$P < 0.003$	M = 2.6829 SD = 1.15924	M = 3.7825 SD = 1.36370
I currently feel inferiority	$P < 0.003$	M = 1.7744 SD = 0.95820	M = 2.3354 SD = 1.20033
I currently feel lucky	$P < 0.003$	M = 2.7378 SD = 1.37153	M = 2.252 SD = 0.96905
I currently feel superiority	$P < 0.003$	M = 2.1890 SD = 1.13438	M = 1.5935 SD = 0.68140
I currently feel resentment	$P < 0.003$	M = 1.8841 SD = 1.08843	M = 2.3313 SD = 1.28702
I am pleased by how things have turned out for the other participant	n.s	M = 3.0671 SD = 1.15654	M = 2.5264 SD = 1.06547
I would like to be in the other player's shoes	$P < 0.003$	M = 2.0061 SD = 1.04206	M = 2.9329 SD = 1.40809
I currently feel relief	$P < 0.003$	M = 2.8598 SD = 1.09979	M = 2.1565 SD = 0.74633
What happened to the other gives me satisfaction	$P < 0.003$	M = 2.6463 SD = 1.14697	M = 1.9228 SD = 0.58760
Color-related questions[a]	n.s	M = 4.4654 SD = 0.81217	M = 4.436 SD = 0.80621

Bonferroni correction for multiple comparisons was used.
[a]Four color-related questions appeared to conceal the purpose of the task (e.g., "I prefer blue over other colors" and "Pink color calms me.").

consequence of the other player's choice and vice versa. After each decision, the amount of money won (or lost) by the participants was displayed, followed by the amount of the other (putative) player's winnings (or losses). Before the experiment, the participants were informed about the possible amount of money they may gain or lose in each trail (ranging from \$4 gain to \$4 loss). Additionally they were told that they would receive the amount of money they gained at the end of the game. The game was preprogrammed such that the accumulative amount of money won at the end of the game was 4 Shekels (\$1), while the other putative player won 6 Shekels (\$1.5). The game included 16 events (8 relative losses, 8 relative gains). The game was programmed such that the amounts of gains and losses were presented randomly.

To validate the social dimension of the task it was necessary to assess whether subjects actually believed in the existence of the other player. They were asked to fill out a short questionnaire at the end of the experiment which consisted of questions of multiple choice answers concerning the other player (e.g., what do you think was the age of the other player: (1) 20–30 (2) 31–40 (3) 41+ (4) There was no other player). Participants who exhibited suspiciousness about the existence of the other player were excluded from the analysis.

To assess the emotions evoked by each trial, the participants completed a computerized questionnaire (see Table I) including 18 items, of which 13 were adapted from the depression adjective checklist (DACL) [Lubin, 1981] and from previous studies assessing fortune of others emotions [Brigham, 1997; Smith et al., 1996; Van Dijk et al., 2006]. Each item presented an emotion, and participants were asked to rate how well this emotion reflected their feelings at that particular moment on a scale from 1 (not at all) to 7 (extremely). It should be noted that there is a similar term to schadenfreude in Hebrew ("simha la-aid") which is well known to Hebrew speakers. The additional five items were statements about the participants' feelings toward different colors (e.g., "Yellow makes me feel uncomfortable"), which were added to disguise the purpose of the experiment.

Experiment 2—The Neural Bases of Relative Rewards

Subjects

Participants were 18 healthy volunteers, including 10 females and 8 males, ranging in age from 22 to 35 years (M = 26.76, SD = 3.47). All participants were right-handed, Hebrew speaking and had a normal or corrected-to-normal visual acuity. Exclusion criteria included self-reported symptoms of depression, bipolar, panic, or psychotic disorders; substance dependence; epilepsy; and traumatic brain injury. After providing each participant with a description of the study, written consent was obtained and participants were told that they could withdraw at any time. The study was approved by the Tel-Aviv Sourasky Medical Center's Ethics Committee. Two subjects (one male and one female) were excluded from the analysis due to excessive head movements, resulting in a final sample of 16 subjects.

Experimental setting and task

The experiment consisted of four scanning blocks during which the subjects were told that they were playing a game of chance involving color selection with immediate monetary gains and losses. To reinforce the manipulation and persuade the subjects that indeed another player was being scanned in an adjacent scanner, another experimenter was presented to the subject as conducting the experiment simultaneously with an additional subject, scanned in a separate scanner. Furthermore, several intermissions were made between blocks in which the subject was told by the experimenters that they were waiting for the reconnection with the computer in the adjacent scanner before continuing.

Instructions for the game were similar to those described in the behavioral experiment, but excluding the emotional rating. Prior to the actual scanning, the subjects received training on the task in a mock scanner to ensure that they understood the game and could control the response box.

The four scanning blocks took ~8 min each, beginning with an instruction screen of 14 s followed by 16 events of 30 s each. As in the behavioral experiment, the participant's door selection was followed by presentation of the outcome (either a gain, loss, or no change) and then the other (putative) player's outcome. Each scanning block consisted of eight relative gain events and eight relative loss events. Events in each block varied with respect to the disparity between the outcomes of the participant and the putative player. The magnitude of disparities between self and other was counterbalanced between runs, in both relative gains and losses.

In analyzing the data, comparisons were made between events of absolute outcomes and relative outcomes. An absolute outcome was characterized as an event in which the participant's monetary gain or loss was presented (absolute gain, absolute loss, or no gain/no loss).

Each absolute outcome event was followed by a relative outcome event. Relative outcome was characterized as an event in which the participant's outcome was presented adjacent to another player's outcome. Thus, as opposed to the absolute outcome events, the relative outcome events involved comparison with the gains and losses of another participant (social comparison). It is important to note here that the participants were informed about the possible amount of money they may gain or lose in each trial (ranging from $4 gain to $4 loss). This was done to ensure that the absolute outcome event will also involve comparison with other possible outcomes lacking the social aspect of the comparison.

The relative outcome events included unequal monetary outcomes of two types: relative gain (when the participant won more money than the other player) and relative loss (when the participant won less money than the putative player).

Relative gain events consisted of three types of events: (1) an absolute gain presented relative to the other participant's loss/zero gain/loss/smaller gain; (2) an absolute loss relative to the other participant's greater loss; and (3) an absolute zero gain/loss relative to the other participant's loss.

Accordingly, relative loss events consisted of three types of events: (1) an absolute loss presented relative to the other participant's gain/zero gain/loss/lower loss; (2) an absolute gain relative to the other participant's greater gain; and (3) an absolute zero gain/loss relative to the other participant's gain.

Scanning procedure

MR imaging was performed on a 3T whole-body MRI system (GE Medical Systems, Milwaukee) with a real-time echoplanar imaging system. All images were acquired using a standard quadrature head coil. The scanning session included anatomical and functional imaging. Our fMRI acquisition parameters were as follows: TR/TE/Flip angle = 2,200/55/90°; with FOV 24 × 24 cm^2, matrix size 96 × 96. During task performance, behavioral judgments were collected via a fiber optic response pad (Current Designs, PA).

Visual stimulation. All visual stimuli were generated on a PC using E-Prime software (Psychology Software Tools) and were presented via an LCD projector (Epson MP 7200) onto a translucent screen. The images appeared in a mirror positioned ~45° above the subject's forehead, providing a field of view of 40° horizontally × 30° vertically.

fMRI data analysis

The fMRI data was processed using BrainVoyager QX software package (version 1.10.4, Brain Innovation,

TABLE II. Brain regions showing a significant bold response for relative gain vs. relative loss events

	Talairach-coordinates					
	x	*y*	*z*	*N*	*Z*	*P*cor
Brain region						
Left Ventral Striatum	−7	12	−4	115	3.75	<0.0020
Right Ventral Striatum	13	11	3	231	2.55	<0.0200
Right Putamen	18	12	5	300	2.75	<0.0150
Left Middle Occipital Gyrus	−42	−74	3	310	3.3	<0.0050
Medial Frontal Gyrus	20	6	53	176	3.5	<0.0030
Right Middle Temporal Gyrus	55	−49	3	211	4.4	<0.0003

P (FWE corrected) < 0.05, extent threshold 10 voxels.

Maastricht, Netherlands). For each subject, comparison of the raw functional data with the 2D structural scan enabled an estimate of the extent of signal dropout attributable to susceptibility artifact. Functional images were then superimposed on the 2D anatomical images and incorporated into the 3D datasets through trilinear interpolation. The complete dataset was transformed into Talairach space [Talairach and Tournoux, 1988]. Preprocessing of functional scans included head movement assessment, high-frequency temporal filtering, and removal of linear trends. Head motions were corrected by rigid body transformations using three translation and three rotation parameters and the first volume as a reference. Slice scan time correction was performed using sinc interpolation and the first slice as a reference. The temporal smoothing process included linear trend removal and application of high pass filter of three cycles per time course. A 6-mm FWHM Gaussian spatial smoothing was used to reduce noise.

To allow for T_2^*-equilibration effects, the first six images of each functional scan were rejected. The 3D statistical parametric maps were then calculated separately for each subject using standard statistical tests, such as correlation analysis and the General Linear Model. Voxel-based activation measures were collected from the proposed functional systems and further analyzed statistically by SPSS 15.0 and Statistica (version 6).

In this event-related study design, a randomized order of 64 stimuli was presented (32 relative gain events, 32 relative loss events). The intervals of interest for imaging analysis were the periods of viewing the monetary outcome for self ("absolute reward" events) and the periods of viewing one's own outcome relative to the other's outcome ("relative reward/punishment" events).

A random effects model, which estimates the error variance for each condition across subjects, was implemented for group analysis. This procedure provides a better generalization for the population from which data are obtained. The contrast images were obtained from single-subject analysis and entered into the group analysis. A statistical threshold of $P < 0.05$ was used and corrected for multiple comparisons across the whole brain, except for *a priori* hypothesized regions, which were thresholded at $P < 0.001$ (when only clusters involving five or more contiguous voxels were reported). These *a priori* regions of interest included the reward-related regions (i.e., the ventral striatum).

For modeling the BOLD response, 10 types of events were defined according to the payoff events: (1) absolute outcome events contrasted with relative outcome events (Self > 0 + Self < 0 + Self = 0 vs. Self < Other + Self > Other); (2) relative loss events contrasted with relative gain events (Self < Other vs. Self > Other); (3) absolute loss events contrasted with relative loss events (Self < 0 vs. Self < Other); (4) absolute gain events contrasted with relative gain events (Self > 0 vs. Self > Other); (5) absolute gain events contrasted with the relative loss events that followed that absolute gain event (Self > 0 followed by Self < Other); (6) absolute gain events contrasted with the relative gain events that followed the absolute gain events (Self > 0 followed by Self > Other); (7) absolute loss events contrasted with relative loss events (Self < 0 followed by Self < Other); (8) absolute loss events contrasted with the relative gain events that followed that absolute loss event (Self < 0 followed by Self > Other); (9) absolute zero gain/loss events contrasted with the subsequent relative loss events (Self = 0 followed by Self < Other); and (10) absolute zero gain/loss events contrasted with the subsequent relative gain events (Self = 0 followed by Self > Other).

RESULTS

Experiment I

Repeated Measures ANOVA indicated a significant interaction between condition (relative gain, relative loss) and emotion ratings ($F(1,37) = 14.455$, $P < 0.001$). Specifically, planned contrasts revealed that in relative loss events (Self < Other), the participants reported lower ratings of joy and higher ratings of envy as compared to relative gain events (Self > Other) ($P < 0.003$ for both comparisons). Furthermore, analysis of relative gains and losses revealed that even when participants lost money

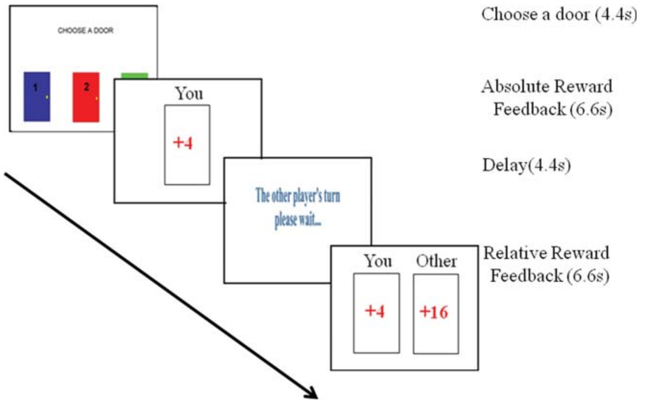

Figure 1.
Schematic depiction of a single trial setting: Three doors were presented from which subjects had to choose one. Followed by the decision, the participant's outcome was presented. After a short interval, the other (putative) player's outcome was presented adjacent to that of the participant. 4.4 seconds of a blank screen followed. In this example, a relative loss condition is shown. An absolute gain of 4 NIS (New Israeli Shekel), equivalent to \$1, was followed by the other's gain of 16 NIS (\$4), thus producing a relative loss. Following each trial, the participant completed a computerized rating scale (from 1 to 7), which included questions about emotions and feelings toward colors (two questions).

(Self < 0), they expressed more schadenfreude and joy if the other player had lost more money (Self > Other) than when they actually won money (Self > 0), but the other player had won more (Self < Other) ($P < 0.05$). These results further support the importance of the relative value of a reward or punishment, implying that sometimes losing may be even more rewarding than winning, provided the other person loses more. To examine gender differences in emotional ratings between conditions, gender was added to the model as the between-subjects factor. The results indicated a main effect of the condition ($F(1,37) = 13.83$, $P < 0.001$) but no gender effect ($F(1,37) = 0.56$, n.s).

As shown in Table I, the results reveal that relative gains were characterized by higher ratings of schadenfreude and emotions related to schadenfreude such as joy, satisfaction with the other's outcome, feelings of superiority, luck, and relief.

Likewise, relative losses were characterized by higher ratings of envy as well as emotions related to envy such as sadness, inferiority, resentment, and feeling less good when compared to the other's outcome. Furthermore, relative gains and losses differed in their ratings of envy and schadenfreude, such that relative gain (Self > Other) was associated with higher ratings of schadenfreude, whereas relative loss (Self < Other) was associated with higher ratings of envy (see Table I).

Experiment 2

Analysis was conducted on 16 subjects who were scanned while playing an fMRI-adapted version of the game of chance. First, we examined whether or not the ventral striatum is activated in relative and absolute losses and gains. As shown in Table II, the ventral striatum indeed showed a significant BOLD response for relative gain vs. relative loss events.

The ventral striatum was selected *a priori* as the region of interest based on previous studies which show this region's role in reward processing [Breiter et al., 2001; Fliessbach, 2007; O'Doherty et al., 2002]. The ROI was defined functionally using the BOLD response in the reward vs. no-reward conditions. As presented above, the task involved two levels of valence of the outcome (gain, loss) and two types of outcome (absolute outcome, relative outcome). Therefore, the primary variables of interest were the valence and the type of outcomes. To obtain measures of the trends and interactions over the different outcomes, a repeated measures analysis of variance was conducted, with the valence and the type of outcome as the within-subjects factors.

This analysis revealed a significant valence outcome effect ($F(1,15) = 16.625$, $P < 0.001$) which indicated that the ventral striatum was more activated in gains than in losses.

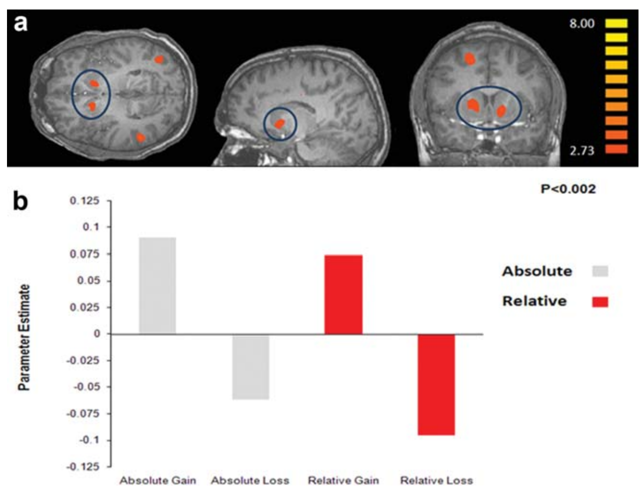

Figure 2.
(**a**) T-Map projected on a single-subject template for the contrast between absolute gains and losses or relative gains and losses with the focus on the activation maximum in the left ventral striatum (TAL: X: −7, Y: 12, Z: −4). (**b**) Parameter estimates for supra-threshold voxels from this contrast showed a similar pattern of activations between absolute gains and losses or relative gains and losses. No significant differences were found between absolute and relative gains or between absolute and relative losses. Parameter estimates represent effect strengths of the condition's influence on the BOLD response. They were then subjected to repeated measures ANOVA.

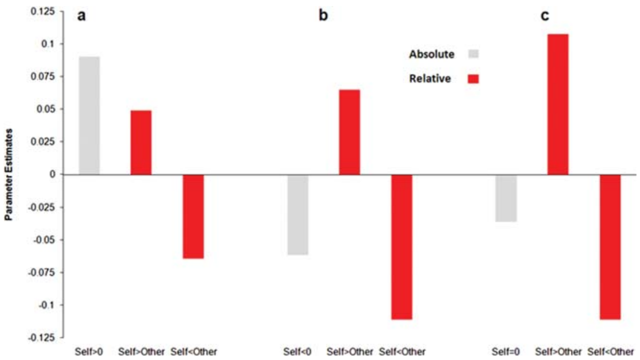

Figure 3.

(**a**) Higher BOLD response in the ventral striatum in the Absolute no gain or loss as compared to relative loss conditions. Lower BOLD response in the ventral striatum in the absolute no gain or loss as compared to relative gain conditions. (**b**) Lower BOLD response in the ventral striatum in the absolute loss as compared to the relative gain conditions. No difference between the absolute loss and relative loss events. (**c**) Higher BOLD response in the ventral striatum in the absolute gain as compared to the relative loss events. No difference between the absolute gain and relative gain events.

No significant type or outcome ($F(1,15) = 0.487$, n.s) or interaction ($F(1,15) = 0.047$, n.s) effects were evident (see Fig. 2).

Analysis of simple effects with planned contrasts indicated, greater ventral striatum activations in the absolute gain (Self > 0) events as compared to the absolute loss (Self < 0) events ($P < 0.05$). Interestingly, this effect was also found when comparing relative gain (Self > Other) with relative loss (Self < Other) events. Specifically, the ventral striatum activations in the relative gain events were greater than in the relative loss events ($P < 0.01$). Furthermore, no significant differences were found in the activations between the absolute gain (Self > 0) and the relative gain (Self > Other) events, indicating that relative reward may be as rewarding as absolute reward. Likewise, the BOLD activations in the ventral striatum were similar in the absolute loss (Self < 0) and the relative loss (Self < Other) events, suggesting that a relative loss is as unrewarding as an absolute loss.

To examine gender differences in the effect of the valence of outcome and the type of outcome, gender was added to the model as the between-subjects factor. The results indicated that gender did not interact either with the valence ($F(1,14) = 0.004$, n.s) or with the type of the outcome ($F(1,14) = 0.005$, n.s) The three-way interaction between valence, type, and gender was also not found to be significant ($F(1,14) = 0.27$, n.s).

To further examine the response of the ventral striatum to the relations between absolute and relative rewards, we performed three separate analyses using the three different absolute outcome events of the task (Self > 0, Self < 0, Self = 0).

This analysis was conducted to examine specifically how the brain reacts to information about the other's gains which follows information about self gains. Thus, each absolute outcome event was compared with the two subsequent relative events (Self < Other, Self > Other). For example, we compared the BOLD response of the absolute gain events (Self > 0) with the relative outcomes that followed these absolute events. We therefore compared absolute gain events with the relative loss events that followed the absolute gains event (Self > 0 followed by Self < Other) and the relative gains events that followed the absolute gain (Self > 0 followed by Self > Other).

Comparison between the absolute gain events (Self >0) with the subsequent relative outcome events

Repeated measures ANOVA indicated a significant ($F(2,14) = 11.354$, $P < 0.001$) difference between the activations in the ventral striatum in the absolute gain events (Self > 0) and either the subsequent relative loss (Self < Other) events or the subsequent relative gain (Self > Other) events. Planned contrasts showed no significant differences in the ventral striatum activations between the absolute gain (Self > 0) and the relative gain (Self > Other) events. However, significant differences were found in the activations between the absolute gain (Self > 0) and the relative loss (Self < Other) events ($P < 0.001$) (see Fig. 3a). These results indicate that the ventral striatum is activated similarly in absolute and relative gain events, whereas its

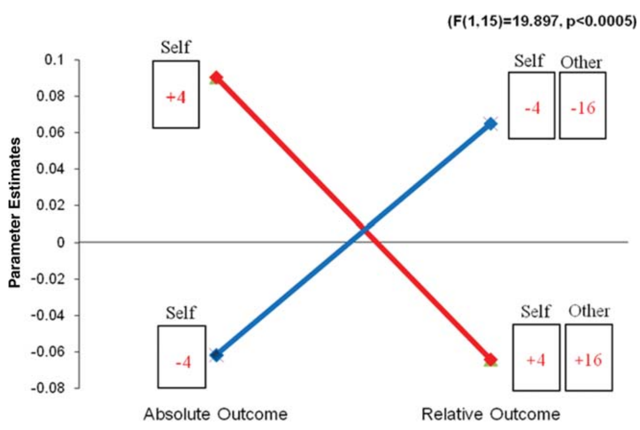

Figure 4.

Ventral striatum activations in the absolute gain (Self > 0) events decreased when this gain was compared to the other's greater gain (Self < Other). Activations in the absolute loss (Self < 0) events increased when the loss was compared to the other's greater loss (Self > Other). No difference was found in the activations between an absolute gain and a relative gain. No difference was found in the activations between an absolute loss and a relative loss.

TABLE III. Brain regions showing a significant BOLD response for relative outcome as compared to absolute outcome events

	Talairach-coordinates					
	x	*y*	*z*	*N*	*Z*	*P*cor
Brain region						
Right lingual gyrus	4	−85	0	247	Inf	<0.0000
Left Superior Frontal Gyrus (BA10)	−17	62	23	180	4.73	<0.0003
Right Superior Frontal Gyrus (BA10)	12	67	18	259	5.26	<0.0001
Right Medial Frontal Gyrus	2	−15	64	271	5.68	<0.0001
Left Precuneus	−2	−59	30	277	7.71	<0.0001
Right Fusiform Gyrus (BA19)	23	−57	−7	135	Inf	<0.0000
Left Fusiform Gyrus (BA19)	−22	−58	−12	185	Inf	<0.0000
Right Inferior Frontal Gyrus	39	20	−18	257	5.71	<0.0001
Left Middle Temporal Gyrus	−38	8	−31	302	4.38	<0.0006
Left Precentral Gyrus	−42	4	37	284	Inf	<0.0000
Right Precentral Gyrus	42	1	38	214	5.42	<0.0001
Right Anterior Cingulate	5	44	9	178	4.25	<0.0007
Left Anterior Cingulate	−8	42	7	183	3.07	<0.0080

P (FWE corrected) <0.05, extent threshold 10 voxels.

activation decreases in relative loss events as compared to absolute gain events.

Comparison between the absolute loss events (Self < 0) with the subsequent relative outcome events

A further repeated measures ANOVA revealed significant ($F(2,14) = 4.35$, $P < 0.05$) differences between the absolute loss (Self < 0) events and either the subsequent relative loss (Self < Other) events or the subsequent relative gain (Self > Other) events. Planned contrasts indicated no significant differences in the activations between the absolute loss (Self < 0) and the subsequent relative loss (Self < Other) events. However, significant differences were found in the activations between the absolute loss (Self < 0) and the subsequent relative gain (Self > Other) events ($P < 0.05$) (see Fig. 3b). These results indicate that the ventral striatum is activated similarly in absolute and relative loss events, while its activation increases in relative gain events as compared to absolute loss events.

Comparison between the absolute no gain events (Self = 0) with the subsequent relative outcome events

The ventral striatum's activations were compared between events in which the subject did not lose or gain (Self = 0) and the subsequent relative events presenting the other's relative gain (Self < Other) or the other's relative loss (Self > Other). Repeated measures ANOVA revealed significant differences between these events ($F(2,14) = 4.06$, $P < 0.05$). As can be seen in Figure 3c, planned contrasts indicated a significant decrease ($P < 0.01$) in the ventral striatum activations in the relative loss events (Self < Other) as compared to the absolute outcome events (Fig. 3c).

To further examine the change in the BOLD response between an event of an absolute gain and the subsequent relative loss as compared to the change between an event of an absolute loss and the subsequent relative gain a repeated measure analysis was conducted. As shown in Figure 4, this analysis indicated a significant interaction effect between the type of outcome (absolute outcome, relative outcome) and the valence of the outcome (gain, loss) ($F(1,15) = 19.897$, $P < 0.0005$). Planned contrasts revealed that activations in the ventral striatum in the absolute gain (Self > 0) events decreased when this gain was compared to the other's greater gain (Self < Other) ($P < 0.001$). Likewise, the activations in the absolute loss (Self < 0) events showed an increase when the loss was compared to the other's greater loss (Self > Other) ($P < 0.05$).

It is important to note here that repeated measures ANOVA indicated no significant differences between the types of relative gain events ($F(2, 28) = 0.31741$, n.s). Similarly, repeated measures ANOVA indicated no significant differences between the types of relative loss events ($F(2,28) = 0.90450$, n.s). This implies that variations in the absolute value of an outcome did not differentiate between corresponding relative gain events or between relative loss events.

Finally, Table III details all the brain regions that showed a significant BOLD response for relative outcome events in comparison to absolute outcome events. As reported in the table, the relative outcome events involved activations in the superior and medial prefrontal cortex, the anterior cingulate bilaterally, the temporal poles, and the fusiform gyrus. These activations do not differ between relative gains or losses.

DISCUSSION

In the present study, we identified differential ventral striatal responses in upward and downward social comparison, despite the fact that the other's gains and losses were irrelevant for the game outcome.

The first experiment demonstrates that events in which participants gain less money than another player are associated with negative emotions such as envy, regardless of the actual disparity between the participant and the other player. Likewise, events in which participants gain more money than another player are associated with feelings of joy and schadenfreude.

The notion that social context can influence the value of monetary reward has been suggested in numerous studies [Ball and Chernova, 2008; Rilling et al., 2002]. In fact, behavioral studies have found that the effect of relative income is even larger than the effect of absolute income [Ball and Chernova, 2008] suggesting that the value of an outcome may depend mostly on its relative social context.

Recent studies suggest a connection between the role of the ventral striatum and the value of a reward in social interactions [Fliessbach et al., 2007; Lieberman and Eisenberger, 2009; Singer et al., 2006]. The results of the present study suggest that a loss can be as rewarding as a gain when another's loss is greater. Likewise, a reward may seem like a loss when the other's gain is greater. Taken together, the results suggest that the ventral striatum plays a role in computing the values of outcome, whether on an absolute or a relative scale. These results not only support previous findings [Elliott et al., 2003; Knutson et al., 2003; Liu et al., 2007] regarding the role of the ventral striatum in both reward and punishment, but also indicate that the ventral striatum responds similarly to absolute and relative gains and losses.

The differential activations in the ventral striatum found here are in line with studies arguing that while reward increases striatal activity, punishment decreases it [Elliott et al., 2003; Knutson et al., 2003; Rilling et al., 2002]. Other studies have suggested that punishment and reward systems are partially dissociable [Liu et al., 2007; Seymour et al., 2005]. The results of the current study support previous results showing increased ventral striatum activations in gains as compared to no gains or losses, and decreased activations in losses as compared to gains or no gains [Breiter et al., 2001; Fliessbach et al., 2007]. Yet, no study to date has demonstrated that absolute gain is processed in a similar pattern as relative gain whereas absolute loss is processed similarly to relative loss.

Interestingly, comparing the activations between an actual gain and a relative gain suggests that even when a person loses money, merely adding information about another person's greater loss may increase ventral striatum activations to a point where these activations are similar to those of an actual gain. In other words, even a loss may seem like a gain when it is compared with another's greater loss. Moreover, winning money elicited activations in the ventral striatum resembling those of an actual loss when compared to another's greater gain, indicating that even a gain may seem like a loss when compared with the other's greater gain. As demonstrated in Experiment 1, the emotional consequences of these comparisons involve envy and schadenfreude. It is thus plausible that these emotions may account for the strong effect that relative reward has, beyond the absolute value of an outcome.

Indeed, the finding of increased activation in the ventral striatum following relative reward is in concordance with a recent study reporting that the activation of the ventral striatum may play a role in envy and schadenfreude [Singer et al., 2006; Takahashi et al., 2009]. Given the results of Experiments 1 and 2 taken together, which indicate that relative monetary loss is associated with lower joy and enhanced envy, while relative gain enhances joy and schadenfreude, we suggest that the experiences of envy and schadenfreude involve differential activation of the ventral striatum. Whereas during envy the activation in the ventral striatum may decrease, indicating that it is an unrewarding experience, during schadenfreude the ventral striatum is activated more prominently, further reinforcing the rewarding nature of this emotion.

The results show that the ventral striatum plays a key role in mediating the value of such relative outcomes and their emotional consequences. Furthermore, the results indicate increased activation in the medial prefrontal cortex and temporal poles in the relative outcome events as compared to the absolute outcome events. The involvement of these areas, previously shown to be important for mentalizing about other people's minds [Gallagher and Frith, 2003], in relative reward, may imply that the mentalizing network is involved in comparing one's own outcome to that of another's. It has been recently shown that the mentalizing system is also involved in envy and schadenfreude [Shamay-Tsoory et al., 2007; Takahashi et al., 2009].

There are several limitations to the present study that need to be acknowledged and addressed. The rather small number of subjects in the imaging study may limit our ability to generalize these findings. Additionally, as observed in Table I the relatively low ratings of envy and gloating may imply that although the manipulation had a significant effect on ratings it was rather subtle. Nevertheless, despite the rather implicit nature of the task, the finding that relative gain provokes schadenfreude and relative loss provokes envy and that these events are related with differential BOLD response in the ventral striatum further emphasizes the ventral striatum's role in mediating these emotions. Future studies should attempt to broaden our knowledge regarding the neural substrates of social comparison and the resulting emotions by focusing on individual, gender, and cultural differences in neural and behavioral responses during social comparison. Furthermore, it is important to further examine the effects of the domain of comparison (e.g., social comparison in a valued vs. non-valued dimension to one's self).

Taken together, it may be suggested that while the medial and superior prefrontal cortex are responsible for processing another person's state of mind, the ventral striatum is responsible for calculating the subjective value of absolute and relative rewards.

It is well established that humans are motivated to seek reward and avoid punishment. Here it is demonstrated that humans are extremely sensitive to social comparison, even to the point that losses may provoke joy when compared to the other's greater loss.

ACKNOWLEDGMENTS

The authors thank Rachel Tomer for her comments on the manuscript.

REFERENCES

Adams JS (1963): Toward an understanding of inequity. J Abnorm Psychol 67:422–436.

Apicella P, Ljungberg T, Scarnati E, Schultz W (1991): Responses to reward in monkey dorsal and ventral striatum. Exp Brain Res 85:945–500.

Apicella P, Scarnati E, Ljungberg T, Schultz W (1992): Neuronal activity in monkey striatum related to the expectation of predictable environmental events. J Neurophysiol 68:491–960.

Ball R, Chernova K (2008): Absolute income, relative income, and happiness. Soc Indicators Res 88:497–529.

Ben-Ze'ev A (1992): Envy and inequality. J Philos 89:551–581.

Ben-Ze'ev A (2000): The Subtlety of Emotions. Cambridge: MIT Press.

Breiter HC, Aharon I, Kahneman D, Dale A, Shizgal P (2001): Functional imaging of neural responses to expectancy and experience of monetary gains and losses. Neuron 30:619–639.

Brigham NL (1997): The roles of invidious comparisons and deservingness in sympathy and Schadenfreude. Basic Appl Social Psychol 19:363–380.

Brosnan SF, De Waal FB (2003): Monkeys reject unequal pay. Nature 425:297–299.

Brosnan SF, Schiff HC, de Waal FB (2005): Tolerance for inequity may increase with social closeness in chimpanzees. Proc Biol Sci 272:253–258.

Delgado MR, Schotter A, Ozbay EY, Phelps EA (2008): Understanding overbidding: Using the neural circuitry of reward to design economic auctions. Science 321:1849–1852.

Elliott R, Newman JL, Longe OA, Deakin J (2003): Differential response patterns in the striatum and orbitofrontal cortex to financial reward in humans: A parametric functional magnetic resonance imaging study. J Neurosci 23:303.

Fehr E, Schmidt KM (1999): A theory of fairness, competition, and cooperation. Q J Econ 114:817–868.

Festinger L (1954): A theory of social comparison. Hum Relat 7:117–40.

Fliessbach K, Weber B, Trautner P, Dohmen T, Sunde U, Elger CE, Falk A (2007): Social comparison affects reward-related brain activity in the human ventral striatum. Science 318:1305–1308.

Gallagher HL, Frith CD (2003): Functional imaging of "theory of mind." Trends Cogn Sci 7:77–83.

Hikosaka O, Sakamoto M, Usui S (1989): Functional properties of monkey caudate neurons. III. Activities related to expectation of target and reward. J Neurophysiol 61:814–832.

Homans GC (1961): Social Behavior: Its Elementary Forms. London: Routledge and Kegan Paul PLC.

Izuma K, Saito DN, Sadato N (2008): Processing of social and monetary rewards in the human striatum. Neuron 58:284–294.

Kawagoe R, Takikawa Y, Hikosaka O (1998): Expectation of reward modulates cognitive signals in the basal ganglia. Nat Neurosci 1:411–416.

Knutson B, Fong GW, Bennett SM, Adams CM, Hommer D (2003): A region of mesial prefrontal cortex tracks monetarily rewarding outcomes: Characterization with rapid event-related fMRI. Neuroimage 18:263–272.

Lieberman MD, Eisenberger NI (2009): Neuroscience: Pains and pleasures of social life. Science 323:890–891.

Liu X, Powell DK, Wang H, Gold BT, Corbly CR, Joseph JE (2007): Functional dissociation in frontal and striatal areas for processing of positive and negative reward information. J Neurosci 27:4587–4597.

Lubin B (1981): Depression Adjective Check Lists: Manual. San Diego, CA: Educational and Industrial Testing Service.

O'Doherty JP, Deichmann R, Critchley HD, Dolan RJ (2002): Neural responses during anticipation of a primary taste reward. Neuron 33:815–826.

Ortony AA, Collins AA (1988): The Cognitive Structure of Emotions. New York: Cambridge University Press.

Parrott WG (1991): The emotional experiences of envy and jealousy. In: Salovey P, editor. The Psychology of Jealousy and Envy. New York: Guilford Press. pp 3–30.

Rilling J, Gutman D, Zeh T, Pagnoni G, Berns G, Kilts C (2002): A neural basis for social cooperation. Neuron 35:395–405.

Rolls ET (2005): Emotion Explained. Oxford: Oxford University Press. 584 p.

Seymour B, O'Doherty JP, Koltzenburg M, Wiech K, Frackowiak R, Friston K, Dolan R (2005): Opponent appetitive-aversive neural processes underlie predictive learning of pain relief. Nat Neurosci 8:1234.–1240.

Shamay-Tsoory SG, Tibi-Elhanany Y, Aharon-Peretz J (2007): The green-eyed monster and malicious joy: The neuroanatomical bases of envy and gloating (schadenfreude). Brain 130:1663–1678.

Singer T, Seymour B, O'Doherty JP, Stephan KE, Dolan RJ, Frith CD (2006): Empathic neural responses are modulated by the perceived fairness of others. Nature 439:466–469.

Smith RH, Turner TJ, Garonzik R, Leach CW, Urch-Druskat V, Weston CM (1996): Envy and schadenfreude. Person Soc Psychol Bull 22:158.

Stouffer SA (1949): The American Soldier. Princeton: Princeton University Press.

Takahashi H, Kato M, Matsuura M, Mobbs D, Suhara T, Okubo Y (2009): When your gain is my pain and your pain is my gain: Neural correlates of envy and schadenfreude. Science 323:937–939.

Talairach J, Tournoux P (1988): Coplanar Stereotaxic Atlas of the Human Brain. New York: Thieme Medical Publishers.

Van Dijk W, Ouwerkerk J, Goslinga S, Nieweg M, Gallucci M (2006): When people fall from grace: Reconsidering the role of envy in Schadenfreude. Emotion 6:156.

Zink CF, Tong Y, Chen Q, Bassett DS, Stein JL, Meyer-Lindenberg A (2008): Know your place: Neural processing of social hierarchy in humans. Neuron 58:273–283.