Research Article

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Neural correlates of opponent processes for financial gains and losses

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Abstract

Objective: Functional imaging studies offer alternative explanations for the neural correlates of monetary gain and loss related brain activity, and their opponents, omission of gains and losses. One possible explanation based on the psychology of opponent process theory suggests that successful avoidance of an aversive outcome is itself rewarding, and hence activates brain regions involved in reward processing. In order to test this hypothesis, we compared brain activation for successful avoidance of losses and receipt of monetary gains. Additionally, the brain regions involved in processing of frustrative neutral outcomes and actual losses were compared in order to test whether these two representations are coded in common or distinct brain regions.

Methods: Using a 3 Tesla functional magnetic resonance imaging machine, fifteen healthy volunteers between the ages 22 to 28 were scanned for blood oxygen level dependent signal changes while they were performing a probabilistic learning task, wherein each trial a participant chose one of the two available options in order to win or avoid losing money.

Results: The results confirmed, previous findings showing that medial frontal cortex and ventral striatum show significant activation ($p<0.001$) not only for monetary gains but also for successful avoidance of losses. A similar activation pattern was also observed for monetary losses and avoidance of gains in the medial frontal cortex, and posterior cingulate cortex, however, there was increased activation in amygdala specific to monetary losses ($p<0.001$). Further, subtraction analysis showed that regardless of the type of loss (i.e., frustrative neutral outcomes) posterior insula showed increased activation.

Conclusion: This study provides evidence for a significant overlap not only between gains and losses, but also between their opponents. The results suggested that the overlapping activity pattern in the medial frontal cortex could be explained by a more abstract function of medial frontal cortex, such as outcome evaluation or performance monitoring, which possibly does not differentiate between winning and losing monetary outcomes.

Keywords: Medial frontal cortex, monetary gain, monetary loss, neuroimaging, opponent process theory

INTRODUCTION

Understanding how the brain encodes, represents, and manipulates processes that are involved in potential gains and losses is essential for understanding goal directed behavior (1). Over the last decade, a wealth of human neuroimaging studies, designed to test reinforcement based theories of learning, revealed much about neural systems mediating rewards and punishments (2-5). Moreover, a convincing number of human brain imaging studies showed learning related changes in brain activity in the midbrain dopaminergic system and the ventral striatum (6-8). However, in the reinforcement-learning context, less is known about how the reward system interacts with neural mechanisms involved in avoidance learning (9). More recently, studies showed controversial results, with some revealing partially overlapping brain regions for both gains and losses and others showing distinct neural systems (2, 10-15). These conflicting results, might be partially explained by the differences in study design for example, in avoidance learning, successful avoidance of monetary losses (negative reinforcement) might activate similar brain regions as receiving gain outcomes (positive reinforcement), due to the context in which both paradigms change one's financial status in the same desired direction (Figure 1).

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The two main theoretical frameworks which suggest an explanation for the connection between avoidance and approach behavior are two-factor theories and opponent process theories of conditioning (16-20). According to the Solomon's opponent process theory, termination of a positively valenced situation might be associated with the opposite valence hedonic response (20). Similarly, terminations of negatively valenced situations are associated with positive valence. Based on opponent processes theory, explained above, Kim et al. suggested that successful avoidance of aversive outcome, acts like a rewarding outcome and activates similar brain regions as monetary gains in the medial frontal cortex (21). Additional evidence also supports this hypothesis, which showed that medial frontal cortex is involved in termination of a painful events (2). Based on this evidence, we hypothesized that if avoiding an aversive outcome is itself rewarding, then missing a rewarding outcome might be aversive. Similarly, Amsel's frustration theory proposes that the omission of an expected reward is a form of abstract punishment (22, 23). Neural correlates of frustration due to missing of rewarding outcomes have been shown to increase activity in the insular cortex (24). For the current study, we hypothesized that receiving a monetary reward might activate similar brain regions as successful avoidance of losses, while receiving monetary losses could activate similar brain regions as experiencing frustrative neutral outcomes (non-reward). In order to examine this hypothesis, we used an event-related functional magnetic resonance imaging (fMRI) study with a reinforcement-learning paradigm in order to test the neural correlates of opponent process theory in learning.

METHODS

Participants

Fifteen healthy normal right-handed volunteers (8 male, 7 female; mean age:25, range: 22-28) all students of University of Hertfordshire were recruited to the experiment, but only 12 participants (6 male, 6 female) were included in the analysis. Three of the participants were excluded from the analysis, one due to excessive movement inside the scanner (movement greater than 6 mm) and the others due to the loss of behavioral data. The participants were pre-assessed to exclude those with a prior history of neurological and psychiatric illness. All participants filled a written informed consent form before fMRI measurements, and all received both written and verbal requests, which outlined the purpose and nature of the study, before the fMRI session. They were debriefed after the experimental session, and paid according to their performance in the task. The study was approved by the Bedfordshire NHS Ethics committee board (Date:24.06.2008 Decision Number:06/Q0202/21).

Task

The whole experiment consisted of 3 sessions, separated by an average of ~2 min. In each session, the color of the stimuli indicated the trial type, except for the neutral trials in which it remained the same for all three sessions (Figure 2). Within the sessions, each trial was an instrumental learning task involving monetary feedback. Each trial began with simultaneous presentation of one of three pairs of stimuli (all symbols were letters taken from Agathodaimon font), and each pair of symbols signified the onset of three trial types: Gain, Loss and Neutral, whose occurrence was fully randomized throughout the experiment. The participant's task in each trial was to choose one of the two symbols by selecting the right or the left key button from the response box. For each pair of stimuli, the position of the symbols (right or left) was also counter balanced within the session. When the trials started, a fixation cross (null event) was shown at the center of the screen for 0.5 s indicating the start of the trial. This was replaced by the conditional stimulus (two symbols) presented on the screen for 4 s to the left and right of where the cross-had previously been. The participants had to choose which symbol would be rewarded in this 4s time period. Once the symbol was selected, the chosen symbol was shown by an arrow for 0.5 s followed by the outcome. Between the selected symbol and outcome screens, there was a random inter stimulus interval (ISI) of about average

Figure 1. Arrows shows the way in which the frequency of behavior can be made to increase (arrow head pointing up) or decrease (pointing down) by manipulating the outcome

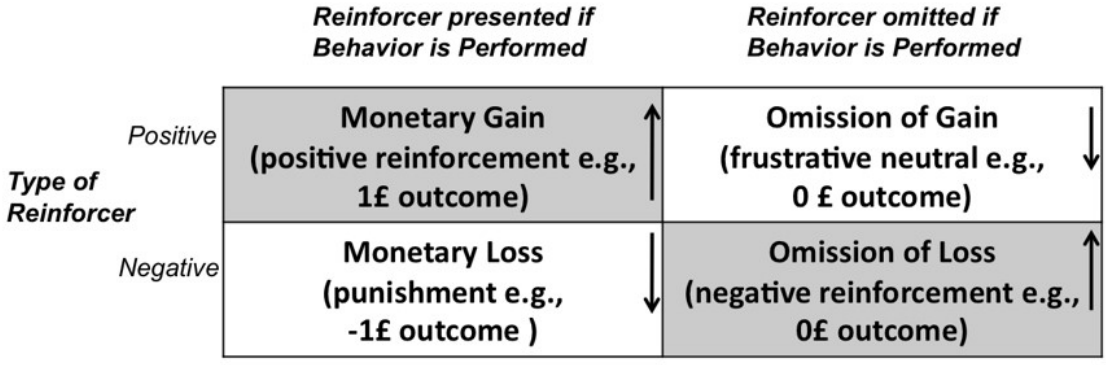
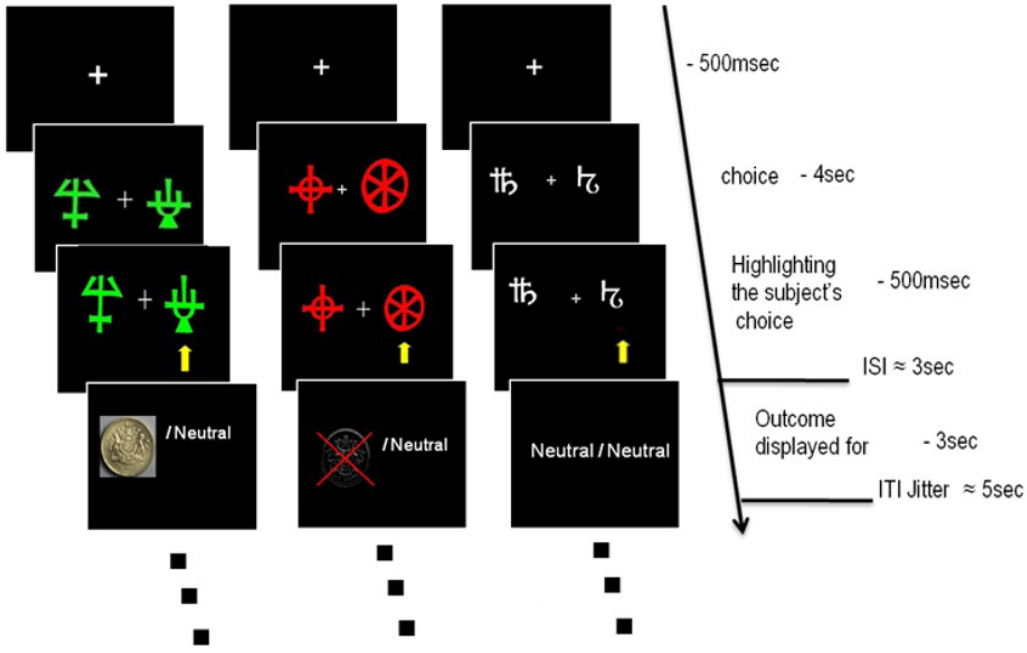


Figure 2. Schematic of the experimental design. Gain trials (green), Loss trials (red) and Neutral trials (white) were represented in different colors and symbols



~2s for the scanner trigger. The outcome for the participants' choice gain (£1), losses-(-£1) and neutral was shown on the screen for 3 s. When the participants failed to press either button they were instructed at the outcome feedback that they will receive a neutral outcome for the gain pair, or (-£1) for the loss pair. All three trials types were pseudo randomly intermixed throughout the sessions. In the gain trials, when the participants choose the correct symbol (high probability option) then they received monetary reward with 0.8 probability and received neutral feedback with a probability of 0.2. On the other hand, following the choice of incorrect symbol (low probability option), participants received a reward with a probability of 0.2 and neutral outcome with a probability of 0.8. Similarly on the loss trials, if participants chose the correct / optimal symbol (high probability option), they received neutral outcome with 0.8 probability, and a loss outcome with a probability of 0.2, whereas the choice of the incorrect symbol (low probability option) gave a loss of (-£1) with probability 0.8, and a neutral outcome with probability 0.2. On neutral trials, participants always received a neutral outcome independent of the symbol choice. All participants underwent three ~13 min scanning sessions, each consisting of 60 trials (20 trials per condition). Prior to the experiment, participants were instructed that they would be presented with three pairs of stimuli in which the colour of the stimuli would indicate whether it was a gain, loss or neutral trial. They were also instructed that depending on their choices, they would win or lose money or the outcome would be neutral. They were not told which colored pair of stimuli was associated with a particular type of outcome. All participants were instructed to win as much as possible. Before the experiment, they were told that they could earn a maximum of £30 if they choose the correct response in all trials; otherwise, their earnings would depend on their performance in the experiment.

Functional Magnetic Resonance Image Acquisition

The functional imaging was conducted using 3-Tesla MRI scanner (Siemens Magnetom, Erlangen, Germany) to acquire gradient echo T2* weighted echo-planar (EPI) images with blood oxygen level dependent (BOLD) contrast (3x3x3-mm voxel size). Imaging parameters were optimized to minimize signal dropout in medial ventral prefrontal and anterior ventral striatum: we used a tilted acquisition sequence at 30° to the anterior commissure - posterior commissure line (25). Each volume was comprised of 36 axial slices of 3–mm thickness and 3-mm in plane resolution with a TR time (repetition time) of 3s. The flip angle was 90 degrees. T1 weighted structural images (1x1x1-mm voxel size) were also acquired for each participant. Head movement was minimized by head padding.

Functional Magnetic Image Analysis

Image analysis was performed using Statistical Parametric Mapping (SPM8) (Wellcome Department of Imaging Neuroscience, Institute of Neurology, London, United Kingdom) software. For all participants, the images were realigned according to the first volume in order to correct for motion in the scanner. For all participants, anatomical images were co-registered to functional EPI images, and were normalized to a standard EPI template. Spatial smoothing was applied using a Gaussian kernel with full width half-maximum of 8 mm for each participant's data.

RESULTS

Behavioral Results

Over the course of the experiment, participants showed significant preference for the higher probability rewarding option compared to non-rewarding option, $t_{(11)}$= 21.06, p<0.001, two tailed in the gain trials (Figure 3). Additionally, the high probability option in the gain trials were chosen more often than neutral options in the neutral trials, $t_{(11)}$= 11.13, p<0.001, two tailed. Participants also avoided choosing the high probability loss option $t_{(11)}$= 5.48, p<0.001, and hence showed successful avoidance of monetary losses. Moreover, probability of choosing the high probability loss option was significantly lower than choosing neutral option in the neutral condition, $t_{(11)}$= 4.69 p<0.001 two tailed, indicating that participants show successful avoidance of monetary losses. As expected, participants' preference for choosing options in the neutral condition was not significantly different to chance, significance for the least and most frequently chosen option were $t_{(11)}$ = -1.19, p>0.05, two-tailed. Analysis of the mean reaction time (RT) taken for participants to make a choice in the avoidance and reward conditions revealed that participants had significantly shorter RTs for reward trials than avoidance trials $t_{(11)}$ = 3.45, p<0.05, two-tailed; and significantly shorter RTs for reward trials than neutral trials $t_{(11)}$ = 5.46, p<0.001, two-tailed. Also comparison of mean RTs between the avoidance trials and neutral trials revealed that participants responded to avoidance trials significantly quicker than to neutral trials $t_{(11)}$ = 2.19, p<0.05, two tailed.

Functional Magnetic Resonance Image Results

Individual time series data were analyzed using a general linear model (26). Regressors of interest were rewarded responses on gain trials (£1), non-rewarded response in gain trails (neutral outcome), non-loss outcomes (£0) in the loss trials, loss outcomes (i.e. -£1) in the loss trials, and neutral trials were modeled with separate box car functions during the time of receipt of reward outcome. The motion parameters calculated for the realignment procedure were also included in the model to account for the residual effects of movement (covariates of no interest). All three sessions were included in the analysis of individual results. A random effects analysis for all 12 participants was performed for the group level analysis and the peak coordinates of the significant activations were reported in Montreal Neurological Institute (MNI) coordinates.

Regions Involving Receipt of Reward and Loss Omission

The experimental design allowed us to look at brain regions (whole brain analysis) involved in reward outcomes and loss omissions. Reward outcome is modelled as the contrast in which participants get a £1 reward in the gain trials, whereas loss omission is the contrast in which the participants get a neutral outcome in loss trials, and. We first examined the regions involved uniquely in processing the contrats of reward receipt but not omission of losses (reward receipt > omission of losses) in order to see whether there is a difference between the two processes ie reward gain vs loss ommission. Direct comparison of these contrasts revealed activity in the

Figure 3. Behavioral data averaged across all 12 participants showing the percent of responses allocated to high (0.8 probability of gaining or losing money) and low (0.2 probability of gaining or losing money) probability options for the gain, loss and neutral conditions. Participants choose the high probability rewarding option significantly more in reward trials than the neutral option in the neutral trials and they choose the low punishing option significantly more than the neutral option in the neutral trials (** indicates significance p<0.001, two-tailed, * indicates significance p<0.05, two-tailed)

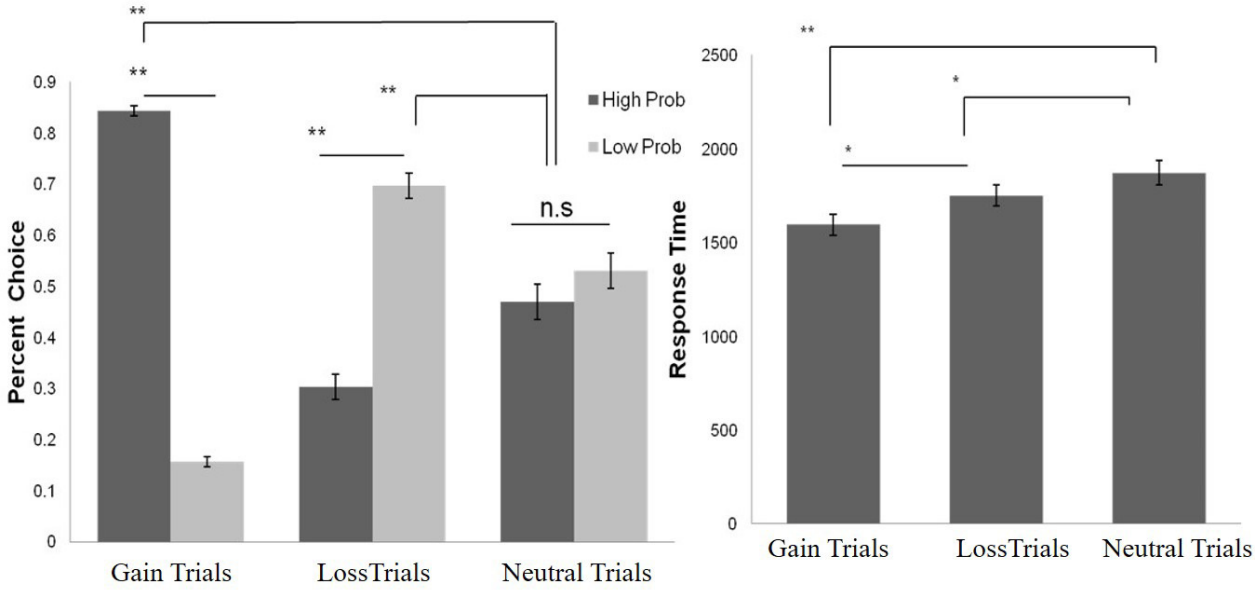
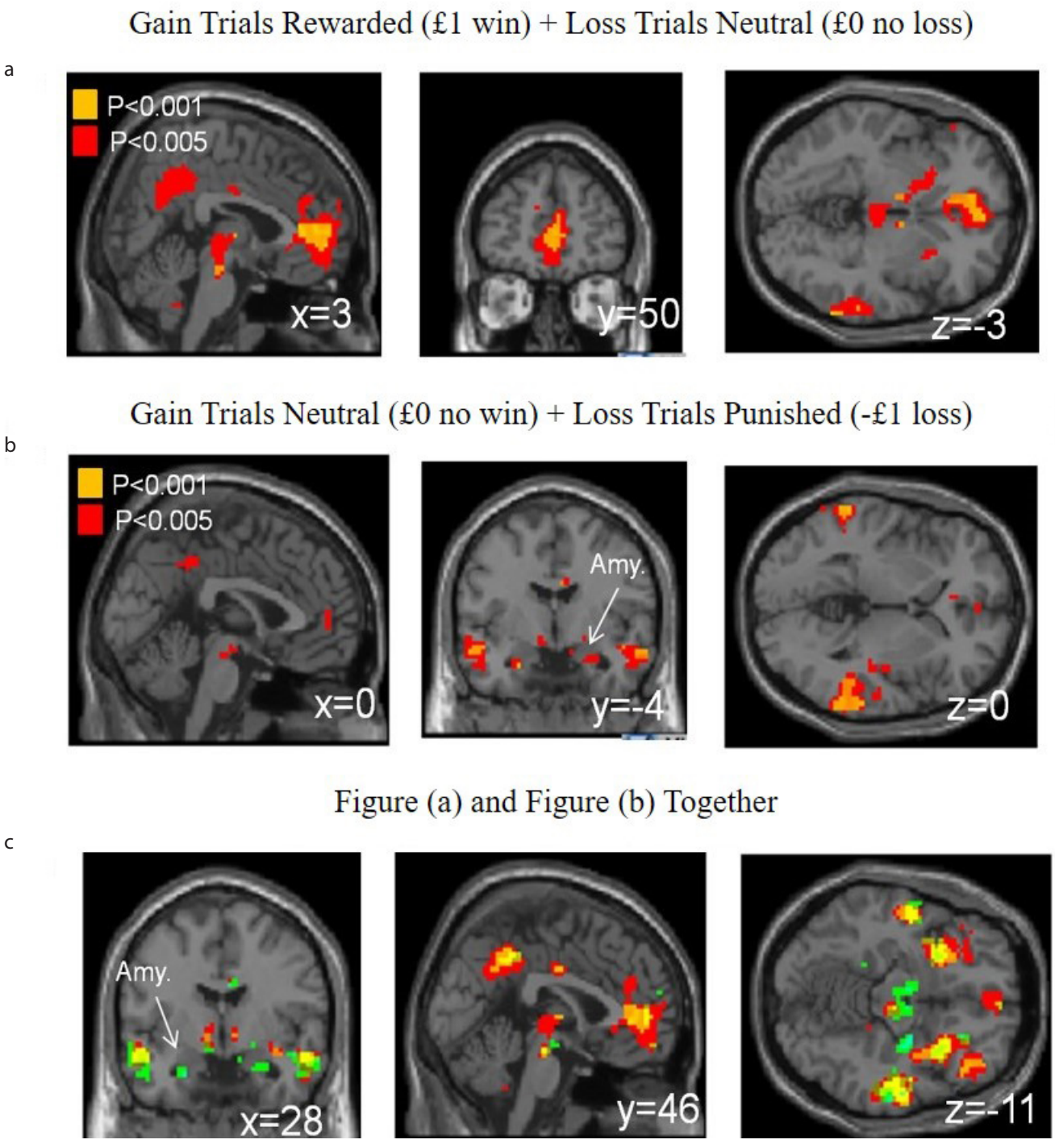


Figure 4. a-c. Areas of whole brain showing significant activity during the outcome period for the probabilistic learning task. Group random effects results are shown superimposed on a coronal, sagital and axial single subject T1 weighted image (at the MNI coordinate indicted in the bottom right corner of image). Significant effects are shown at p<0.001 in orange and p<0.005 in red (to show the full extent of activation). (a) Group results are shown for the conjunction contrast for gain outcome received and loss omission. (b) Group results are shown for the conjunction contrast for gain omission and loss outcome punished. (c) Figure a and b in conjunction. Orange and red regions depict reward related areas green and yellow regions depict monetary loss related regions



right medial frontal gyrus (T=6.06, MNI, x=30, y=5, z=52) a region previously shown to be involved in coding reward gains (42) and left sub-gyral (T=4.46, MNI, x=-18, y= 26, z=46) with p<0.001 uncorrected (no other areas showed significant activity at this *p*-value). We also examined the opposite contrast (omission of losses > reward receipt), where no significant activation found at the level of p<0.001 (uncorrected).

Regions Involving Receipt of Loss and Omission of Gain Outcome

We also investigated the brain regions that contrast between receipt of loss outcomes and omission of gain outcomes. We first examined the regions involved only in receipt of loss outcomes but not omission of gain outcomes (receipt of loss > omission of gain) and vice versa (omission of gain > receipt of loss). Neither of these contrasts showed significant activity at p<0.001 (uncorrected).

Overlapping and Distinct Regions for Gains and Losses

We first performed a conjunction analysis to identify the regions involved in gain trails that are rewarded, and omission of losses. Consistent with a previous study, we found activations mainly in medial frontal cortex (MNI, x=-6, y=35, z=4) with peak in anterior cingulate cortex and medial frontal cortex activity at (MNI, x=6, y=44, z=-2) (27). This region, showed increased BOLD response not only for reward receipt but also omission of losses at p<0.001 (uncorrected). For the same contrast, additional activation was also found in the posterior cingulate gyrus (MNI, x=-3, y=-10, z=34), bilateral ventral striatum (MNI, x=26, y=17, z=-5.5) and (x=-20, y=17, z=-5.5), bilateral orbito-frontal cortex (MNI, x=30, y=14, z=17) and (MNI, x=-36, y=17, z=20) midbrain (MNI, x=6, y=-28, z=5) and ventral precuneus with a peak voxel activity in (MNI, x=-3, y=49, z=46).

Additionally, in order to depict the areas with greater response to receipt of rewards and avoidance of losses (neutral outcomes), but not for omitted rewards and monetary losses, we performed a subtraction analysis between the two contrast. We found activity in the right putamen (T=3.24, MNI, x=21, y=6, z=13), bilateral pulvinar (T=5.52, MNI, x=27, y=-28, z=1; T=5, MNI, x=21, y=-31, z=-2), Brodmann area 6 (pre-motor cortex) (T=3.89, MNI, x=-3, y=-1, z=53) and left Brodmann area 11 in the ventro-lateral orbito frontal cortex (T=4.04, MNI, x=-24 y=47 z=-11) p<0.001 (uncorrected) (Figure 5). Finally, in order to depict the areas more responsive to aversive loss outcomes and frustrative neutral outcomes compared to rewarded gain and loss omission trials, we looked at the contrast (con 3 + con 6 – con 2 – con 5). Only two regions showed significant activity p<0.001 (uncorrected), in the left insula (T=3.26 x=-42, y=29, =z=10) and the brainstem (T=4.33 x=12, y=-31, z=-20) (Figure 5). This indicates that left insula is specific to negative outcomes. No other brain regions showed significant activity at p<0.001 (uncorrected).

DISCUSSION

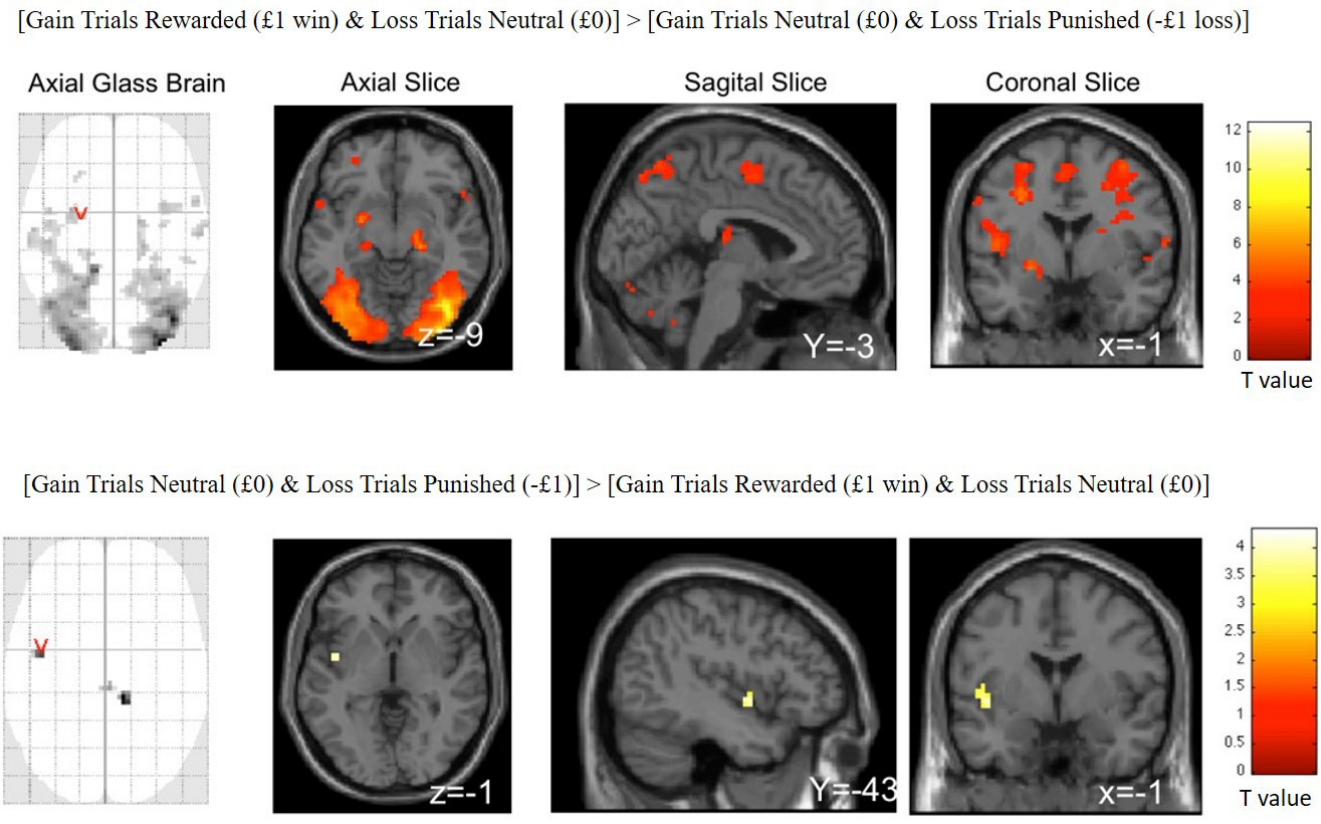
Learning of stimulus-outcome relations critically depends on processing of rewards and punishments at various stages of a reinforcement-learning task. In the current study, we not only tested which brain regions are involved in monetary gain as reward outcome and monetary loss as punishment outcome, but also which brain regions are involved in omissions of losses (potential reward) and omissions of gains (potential punishment). We also addressed the issue of whether monetary gains and losses are coded in the same regions in an integrated way or with separate regions in a segregated way. The results showed that gains and losses activate both overlapping and distinct regions in the human medial frontal cortex. Activity in these region not only increased for gains and losses, but also increased for their opponents. These results suggest that during the outcome retrieval, some region of medial frontal cortex and cingulated cortex responding to reward receipt and avoidance of losses show overlapping activations with received punishments and missed reward outcomes in the medial frontal cortex.

Previous studies showed that lesions to ventromedial frontal cortex disrupt reversal learning that requires a shift in behaviour in response to negative feedback as well as disrupting learning from negative feedback in probability learning tasks (28-31). It is possible that medial frontal cortex is involved in evaluating feedback regardless of its type (negative or positive). In addition, we found a distinguishing activity in the amygdala between gain trials in which participants received neutral outcome and avoidance trials with punishing outcomes. Supporting this finding, Yacubian et al. showed amygdala activity when they compared the neural correlates of monetary losses with neutral outcomes ie on both types of aversive trial (32). Hence, it is well recognized that the amygdala is involved in aversive learning (32).

In findings regarding striatum, there is evidence that supports activation of nucleus accumbens correlated with aversive stimuli (3, 4, 33-35). However, a recent meta-analysis study showed both reward and loss related activity in the striatum (36). This meta-analysis finding is coherent with the current findings since both gain and loss outcomes activated striatum and the midbrain. Theoretically, activation in the striatum, more specifically ventral striatum, has been previously reported to correlate with the salience of the stimulus presented (37). As discussed earlier, it is possible that activation in these regions is modulated by the salience of rewards and punishments.

Furthermore, there is neurobiological evidence to confirm that the underlying motivational processes in monetary loss share strong similarities with physical pain with the activity most commonly seen in the insular cortex (2, 38). In our study, we found insular cortex activity when the punished outcomes were subtracted from the neutral outcomes. Re-

Figure 5. The figure on the top shows brain regions that show higher activation for the conjunction of gain trials rewarded (+£1) & Avoidance trails neutral outcome (£0) compared to the conjunction of gain trials neutral (£0) & avoidance trials punished (-£1). The figure on the bottom shows brain regions that show higher activation for conjunction of gain trials rewarded (+£1) & loss trails neutral outcome (0£) compared to conjunction of gain trials neutral (£0) & avoidance trials punished (-£1). Group results are shown superimposed on axial, sagittal and coronal slices at the MNI coordinates indicated below. Significant effects are shown at p<0.001 (uncorrected)



cently, Pessiglione et al. and Seymour et al. showed that monetary loss activates the insular cortex, while the activity in this region was previously shown to be correlated with expected pain (39, 40). In contrast, the activity in the insular cortex can be interpreted as a response inhibition failure in our study; because participants were trying to avoid losses and they may have thought that, their negative feedback was due to their inability of avoiding the aversive option (41). Finally, we found that amygdala selectively responded to loss outcomes compared to rewarded outcomes. Previous studies showed that amygdala is involved in monetary losses and this region might control the 'fight or flee' response in a gambling task (31).

The current study adds to the existing functional imaging literature regarding the involvement of some regions of medial frontal cortex and striatum involved in processing of both monetary gains and monetary losses. The findings also suggest that both avoiding a loss outcome and getting a rewarding outcome activate similar regions in the medial frontal cortex, but to differential degrees.

The findings have important implications for understanding monetary loss outcomes, because the activations found in the insula for monetary losses show overlapping regions with other imaging studies that examined the phenomenological aspects of pain processing. Finally, the results showed that the bilateral amygdala is important for processing monetary losses.

On the other hand, the general opponency relationship between gains and losses suggests that processing of financial losses need additional activation in the bilateral amygdala.

Ethics Committee Approval: Ethics committee approval was received for this study from Bedfordshire NHS Ethics Committee board (Date:24.06.2008 Decision Number:06/Q0202/21).

Informed Consent: Written informed consent was obtained from healthy participants who participated in this study.

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Author Contributions: Concept – B.E., J.D.; Design - B.E., J.D.; Supervision - J.D.; Materials - B.E.; Data Collection and/or Processing -

B.E.; Analysis and/or Interpretation - B.E., J.D.; Literature Search - B.E., J.D.; Writing Manuscript - B.E., J.D., Critical Review - B.E., J.D.

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