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Decision-related loss: Regret and disappointment

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ABSTRACT

Both affective neuroscience and decision science focus on the role of emotions in decisions. Regret and disappointment are emotions experienced with negative decision outcomes. The present research examines the neural substrates of regret and disappointment as well as the role of regret and disappointment in decision making. Experiment 1 compared the subjective experience of regret and disappointment. Participants selected one of two gambles and received different types of feedback during the outcome phase. Despite identical nominal losses, regret induced a more intense dislike of the outcomes and a stronger desire to switch choices than disappointment. Using functional magnetic resonance imaging, Experiment 2 examined the neural correlates of regret and disappointment. Both regret and disappointment activated anterior insula and dorsomedial prefrontal cortex relative to fixation, with greater activation in regret than in disappointment. In contrast to disappointment, regret also showed enhanced activation in the lateral orbitofrontal cortex. These findings suggest that regret and disappointment, emotions experienced during decision-related loss, share a general neural network but differ in both the magnitude of subjective feelings and with regret activating some regions with greater intensity.

Introduction

Both affective neuroscience and decision science examine the neural underpinnings of decision-related loss. Two types of emotions are often associated with decision-related loss: regret and disappointment. Whereas *disappointment* is experienced when the obtained outcome is worse than expected or hoped, *regret* is experienced when one's decision leads to an outcome that is worse than if one had decided differently. While both disappointment and regret arise from the comparison with unfulfilled expectations, regret has an additional component of responsibility or self-blame for the obtained outcome, as well as a potentially more direct effect on subsequent decision processes. That is, whereas disappointment is relatively free of self-blame because the outcome of the situation is appraised as beyond one's control (Van Dijk and Zeelenberg, 2002a, 2002b), regret typically directs evaluations to the quality of one's decision, leading to self-blame or sense of responsibility over the unfavorable outcome because a different option could have been chosen (Connolly and Zeelenberg, 2002). Behavioral studies of regret and disappointment also have shown that, in contrast to disappointment, regret induces a desire to correct a mistake, undo the event, and get a second chance (Zeelenberg et al., 1998a, 1998b).

Initial evidence using both lesion patients and neuroimaging techniques suggest regional specificity, with medial orbitofrontal cortex (mOFC) implicated in regret, as measured by counterfactual comparisons of outcomes of chosen and unchosen options (Camille et al., 2004; Coricelli et al., 2005). Feeling of disappointment, on the other hand, was related to activations in middle temporal gyrus and dorsal brainstem (Coricelli et al., 2005). Alternatively, it is reasonable to expect that regret and disappointment recruit the same neural circuitry, given that both involve a negative emotion about obtaining a poor outcome. Previous research has shown that lateral orbitofrontal cortex, anterior insula (O'Doherty et al., 2003) and the dorsomedial prefrontal cortex (Dosenbach et al., 2006; Ridderinkhof et al., 2004) are typically involved in negative emotions and negative outcome feedback. If regret and disappointment differ mainly in the magnitude of the experienced emotion, the negative emotions of regret and disappointment would be expected to activate these areas, with greater activation during regret than disappointment because regret entails more self-blame or greater responsibility for an identical loss.

The present research explored the relation of regret and disappointment with decision-related behavior, and examined the neural substrates of regret and disappointment. Determining the role of emotions in decisions would add to our general understanding of decision making processes and has implications for psychiatric problems with decision-related symptoms, including depression and

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obsessive–compulsive disorder. Depression has been associated with increased regret, more reliance on waiting as a decision strategy, and greater risk aversion (Leahy, 2001). Obsessive–compulsive disorder is also associated with indecisiveness, experiencing doubt about whether a particular act has satisfactorily concluded, whether an event may or may not occur, or whether or not the consequences of an action or inaction could be negative (Sachdev and Malhi, 2005). Besides having implications for psychiatric illnesses, research on regret and disappointment also has applications for health-related decisions, e.g., cancer-related decisions (Connolly and Reb, 2005). Research could lead to significant advances in understanding how emotions affect decision making, and how emotions such as regret could alter people's health choices. Finally, regret processes have been shown to play a powerful role in modeling human learning in economic games (Marchiori and Warglien, 2008). Thus, the role of emotion in decision making has important implications for psychiatric disorders, medical decision making, and learning.

Both the psychological mechanisms and the functional neuroanatomy that underlie the similarities and differences between regret and disappointment require further elucidation. In this paper, we report results of two experiments on the behavioral and neurophysiological underpinnings of regret and disappointment. Experiment 1 compared the subjective experience of the two negative emotions. Experiment 2 contrasted the neural activation patterns of regret and disappointment using an event related design. The neuroimaging findings can deepen our understanding of the neurocircuitry linking emotional experience and decision making, and can provide one anchor on which to interpret the behavioral findings.

Experiment 1

This behavioral experiment compared the subjective experience, as well as the behavioral effects of regret and disappointment.

Materials and methods

Participants

Sixteen males and 13 females participated in Experiment 1 (mean age = 20.2, SD = 1.08). All participants completed a written consent form as approved by the institutional review board. Sessions lasted about 1.15 h. The payment scheme was $8 pro-rated per hour plus a bonus based on choices. Mean compensation amount was $15.43.

Design

The experimental design was within-subjects. The gambling paradigm from Mellers et al. (1999) was modified to induce specific emotions in order to examine the behavioral effects of these emotions on subsequent choices. Two two-outcome gambles with different point values (−90 to −10, +10 to +90) and probabilities of winning or losing (10%, 25%, 50%, 75%, and 90%) were shown on the screen; most were mixed gambles offering one gain and one loss. The outcome of every other trial was rigged so that a specified emotion could be induced; the outcomes of the remaining alternate trials were not rigged. This interleaving of rigged and nonrigged trials allowed us to test the effect of the induced emotion on the subsequent decision. For example, a rigged trial is shown on the screen: Gamble 1 has a 50% chance of winning 50 points and a 50% chance of losing 45; Gamble 2 has a 75% chance of winning 30 and a 25% chance of losing 40. This is followed by an unrigged trial: Gamble 3 has a 25% chance of losing 10 and a 75% chance of losing 20, and Gamble 4 has a 90% chance of losing 15 and a 10% chance of losing 35. Each rigged/unrigged pair was presented four times, differing only in the outcome of the rigged trial (elation, disappointment, rejoice, and regret) each time. Because the values and probabilities of winning or losing in each rigged/unrigged pair remained identical across the emotion conditions, we controlled for the values and probabilities of the gambles across emotion conditions.

To experimentally induce a specific emotion e.g. disappointment vs. regret and elation vs. rejoice (two “mirror” conditions in the winning trials), partial and complete feedback was manipulated (Mellers et al., 1999). In half of the rigged trials, outcome feedback (win or loss) was given only for the chosen gamble (*partial feedback*). In the remaining half of the rigged trials, the outcomes for both chosen and non-chosen gambles were shown (*complete feedback*). The partial feedback trials defined the elation trials (the outcome of the selected gamble resulted in a win) and the disappointment trials (the outcome of the selected gamble resulted in a loss). In complete feedback trials, the outcomes of both the selected and unselected gambles induced either ‘regret’ or ‘rejoice’ conditions. The rejoice condition was defined when the selected gamble resulted in a win and the unselected gamble would have resulted in a loss; the regret condition was defined when the selected gamble resulted in a loss and the unselected gamble would have resulted in a win. In contrast to previous studies (Camille et al., 2004; Coricelli et al., 2005; Mellers et al., 1999) where partial feedback trials and complete feedback trials occurred in separate blocks, all trials in the current study were intermixed. This change in design yields trials less accessible to anticipation of feedback type, i.e., whether they receive partial or complete feedback.

Each of the 4 emotion conditions contained 16 rigged trials. Each rigged trial was followed by an unrigged trial, yielding a total of 128 trials. There are 6 possible outcomes for the unrigged trials: regret, rejoice, disappointment, elation, both gambles winning, and both gambles losing. The outcomes of the unrigged trial were selected randomly by the computer program. The order of the trials was also randomly selected by the computer program with the restriction that each rigged trial was followed by its unrigged trial pair; thus all participants received different orders of trials.

A few of the unrigged trials were *variance gambles* to measure risk-seeking tendencies (Yates, 1992). Variance gambles had a 50% chance of winning or losing points with an expected value of zero (e.g., a choice between a 50% chance of winning or losing 60 points vs. a 50% chance of winning or losing 10 points). If the participant chose the gamble with the smaller variance, then the choice would be labeled as *risk averse*; if the participant chose the gamble with a larger variance, the choice would be labeled *risk seeking*.

Procedure

The task was computer-based. Participants were shown pairs of two-outcome gambles, and asked to earn as many points as possible. The points were exchanged for money at the end of the experiment using a conversion formula for bonus compensation. At the beginning of the experiment, the participants learned how the gambles were displayed and completed a practice task. In the experimental task, participants selected a gamble by pressing a key. A white box emerged around the selected gamble on the screen. In the complete feedback condition, pointer(s) appeared on the displays and spun for 2 s for the unchosen gamble and 3 s for the chosen one. Pointers landed in the direction indicating that the participant either won or lost, and stayed there for 3 s. The pointer for the unselected gamble was not shown during the partial feedback condition. After the outcomes were presented, half of the participants made an “Outcome” rating and half made a “Choice” rating. Participants in the “Outcome” rating condition responded to a question asking how they felt about the outcome/s on a 101-point scale, ranging from −50 (Very Much Dislike) to +50 (Very Much Like). This rating was comparable to the question asked in the original studies (Mellers et al., 1997; Mellers et al., 1999). Participants in the “Choice” rating condition answered a question pertaining directly to their desire to change or repeat their choice, which assessed the counterfactual thinking involved in their choice. Based on the knowledge that regret induces a desire to change to a different choice (Tsiros and Mittal, 2000; Zeelenberg et al., 1998a, 1998b), we expect people would have greater intention to change their choice after experiencing regret than disappointment.

Participants who received the "Choice" question expressed their desire to choose a different gamble on a 101-point scale, ranging from −50 (Very Much Disagree) to +50 (Very Much Agree). In both types of ratings, participants responded by pressing a key that moved the cursor from the neutral zero midpoint left toward −50 or right toward +50. After the Outcome or Choice rating, a fixation cross was shown at the center of the screen for 2 s before the next trial began. Cumulative points were shown after every 14 trials. The total cumulative points was converted to a cash bonus, with 1 dollar for each 400 points earned. The average bonus was $3.80 (ranging from $2.75 to $5).

Results

Subjective rating of regret and disappointment

Outcome rating anchors were transformed to make them comparable to Choice ratings, such that higher ratings for both choices and outcomes reflected stronger dislike of the outcome or choice, respectively. Emotion ratings for 4 participants were excluded in the ratings analyses because the participants did not follow instructions in rating their emotions, yielding subjective ratings data from 25 participants. Fig. 1 illustrates that participants disliked their choices and the outcome of their choices to a much greater extent during regret trials than during disappointment trials, [$t(11) = 3.79$ and $t(12) = 3.74$, $p < .005$, for Choice and Outcome ratings, respectively]. A 2×2×2 Mixed ANOVA [Emotion Valence (Positive vs. Negative)×Feedback Type (Partial vs. Complete)×Rating Type (Choice vs. Outcome)] revealed a main effect of outcome valence, such that positive outcomes received lower ratings, $F(1, 23) = 159$, $p < .001$. A significant interaction effect was also observed; the difference between regret and rejoice ratings was larger than the difference between disappointment and elation ratings, $F(1, 23) = 36.30$, $p < .001$. The results suggest that the complete feedback condition induced stronger emotional responses; the rejoice outcomes yielded the best (lowest) ratings, and regret outcomes yielded worst (highest) ratings. There was an interaction effect of emotion valence, feedback, and rating type, such that ratings for disappointment were worse for Outcome ratings than for Choice ratings, $F(1, 23) = 4.65$, $p < .05$. There was no main effect of partial vs. complete feedback on the emotion ratings, $F(1, 23) = 2.25$, *ns*. Participants also reported greater liking of their outcome and a lesser desire to change their choice during rejoice than during elation, [$t(11) = 4.45$, $p < .001$ and $t(12) = 2.51$, $p < .05$ for Choice and Outcome ratings, respectively.]

Decision latency and risk seeking on subsequent trial

The analyses below were based on data from 28 participants; one participant's data was not included in analyzing decision latency because the decision times were all below 1 s (outlier). The average decision time was approximately 4.2 s, across all trials and participants.

Fig. 2 shows the decision time participants took on the subsequent trial after each emotion induction. There was no interaction effect of rating type and emotion condition on decision latency; thus, decision latency data were collapsed in the following analyses. There was a significant difference in decision latency between regret and disappointment, planned contrast $t(27) = 2.43$, $p = .02$, such that participants decided faster after experiencing regret than after disappointment. A 2×2 [Emotion Valence (Positive vs. Negative)×Feedback (Partial vs. Complete)] Repeated Measures ANOVA revealed an interaction effect of emotion valence and feedback types; participants decided fastest after experiencing regret and slowest after experiencing rejoice, $F(1,27) = 10.76$, $p < .005$. Participants also took significantly longer to decide after experiencing rejoice than after experiencing elation, $t(27) = 2.10$, $p < .05$.

No significant difference in risk-seeking or risk-aversion tendency was observed among the four emotion conditions as assessed by

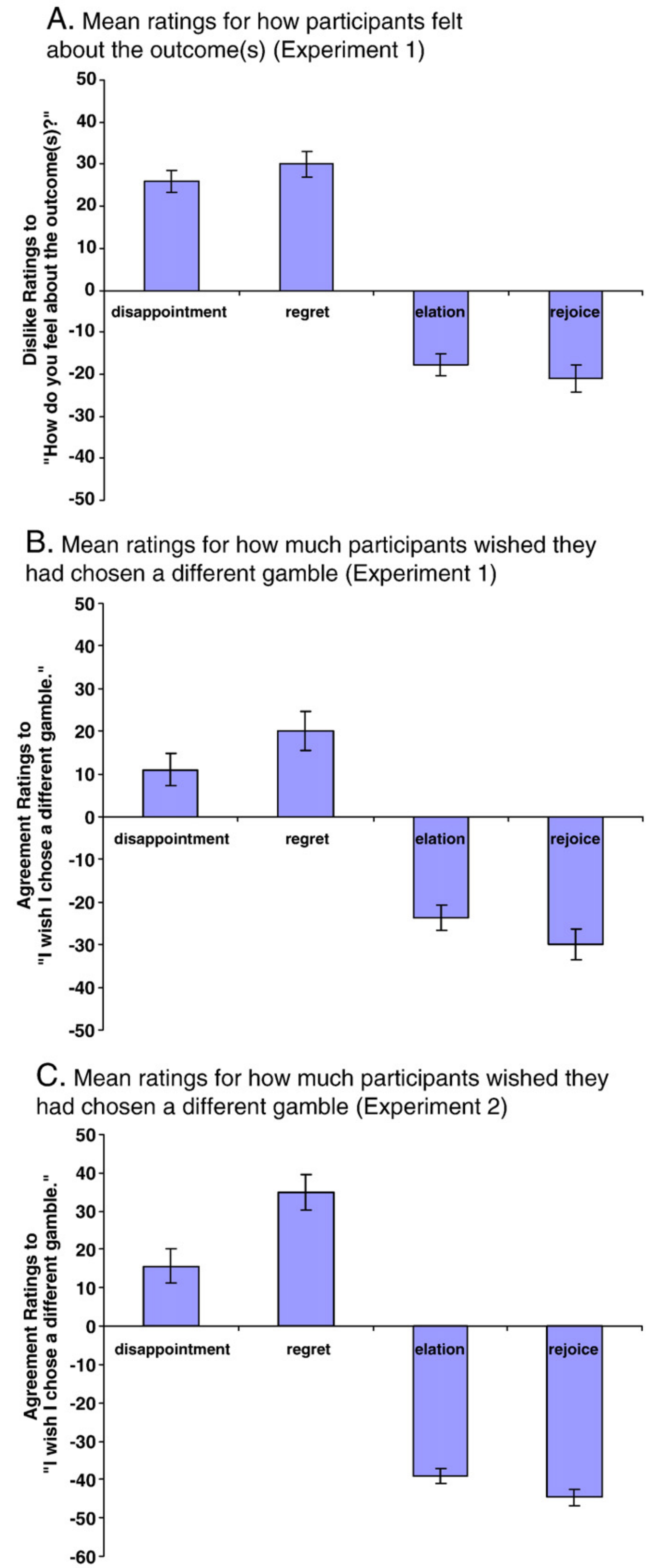

Fig. 1. Participants' average (A) Outcome ratings and (B) Choice ratings after each emotion induction in Experiment 1, and participants' average (C) Choice ratings after each emotion induction in Experiment 2. Standard errors are depicted.

variance gambles. However, risk preference was associated with response time — risk-seeking choice was faster than risk-aversion choice, *Ms* 3614.89 vs. 4127.45 ms, respectively, $t(27) = 2.24$, $p < .05$.

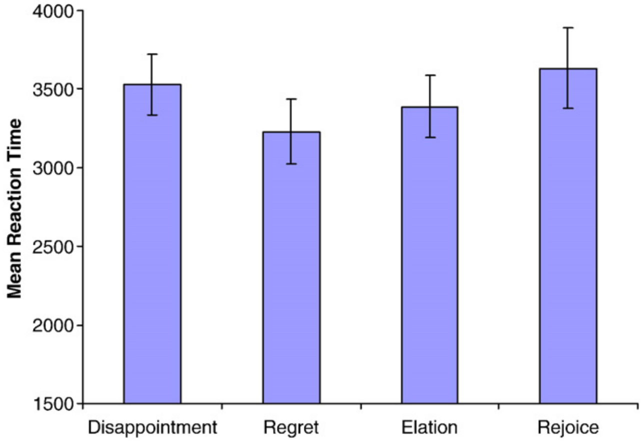

Fig. 2. Mean decision times on the next trial after each emotion induction, Experiment 1. Standard errors are depicted.

Correlations between reaction time and subjective ratings

We computed the correlation between reaction times and subjective ratings in each participant for each emotion condition. The average correlations collapsed across the Outcome ratings and Choice ratings were: 0.18 (Disappointment), 0.20 (Regret), −0.03 (Elation), −.03 (Rejoice), and −.09 (All Trials). In other words, when they took longer to decide and this was followed by the experience of regret or disappointment, they were more likely to report a greater dislike of the outcome or a greater desire to change their choice.

Experiment 2

Experiment 2 used functional magnetic resonance imaging (fMRI) to examine the neural bases of regret and disappointment.

Materials and methods

Participants

Twelve participants with equal gender representation volunteered in Experiment 2 (Mean Age = 21.17 years, SD = 1.19). Participants had normal or corrected-to-normal visual acuity and did not have a current or prior history of head injury or psychiatric illness. All participants completed a written consent form as approved by the institutional review board. Sessions lasted approximately 2 h. The payment scheme was $15 pro-rated per hour plus a bonus based on choices. Mean total compensation amount was $43.88.

Design

The paradigm was similar to Experiment 1 except for two minor modifications to optimize the experiment for the fMRI environment. All trials were rigged and the length of the anticipation, outcome displays, and fixation phases were jittered within each run. After a participant chose a gamble, a spinning pointer(s) appeared for 1, 2, or 3 s for the unselected gamble in the complete feedback conditions, and 2, 3, or 4 s for the selected gamble in both the partial and complete feedback conditions. The spinning duration was randomized within each run.

The outcome was displayed for 3, 4, or 5 s, randomized within each run. Then, participants noted their desire to have chosen a different gamble by pressing one of five buttons attached to a glove worn on the right hand. Each finger represented a degree of agreement, from “Very Much Do Not Agree” (−50) to “Very Much Agree” (+50). The range of agreement was represented with the options −50, −25, 0, +25, +50 on the screen. The rating screen was displayed for 3 s. After the rating, the participant saw a fixation screen for 2, 3, or 4 s, randomized within each run, before proceeding to the next trial.

Emotion outcome conditions were rigged and pseudo-randomized prior to the scan. All participants received the same order of trials and emotion outcomes. There were 7 runs consisting of 18 trials each, for a total of 126 trials throughout the session. Each run included 4 trials of the 4 emotion conditions, plus 2 filler trials. Filler trials included outcomes where both gambles won or both gambles lost. After each run, a cumulative tally was displayed on the screen. Each run lasted 6 min and 10 s. The total scan session lasted approximately 43 min, plus structural and overlay scans. There were 28 trials per emotion condition across the runs. A bonus compensation scheme was adopted. The average bonus earning was $14.50 (ranging from $12 to $20).

Procedure

Each participant was briefed about the study and completed a half hour practice task prior to scan day. Participants learned to identify the values and the probabilities of winning or losing in the gambling task, and also completed two practice runs of the gambling task. During the practice task, the participants rated their desire to change their choice (“Choice” rating) and the degree to which they liked the outcome(s) (“Outcome” rating), by pressing a key corresponding to the scale points: −50, −25, 0, +25, +50 (Very Much Disagree/Dislike to Very Much Agree/Like). Question order was counter-balanced across the participants. Within-subject ratings on both questions permitted a correlation between the two measures. The correlation between Choice and Outcome ratings was significant for 9 out of 12 participants. The average correlation was .57. During the experimental session in the fMRI scanner, only one rating question (“Choice” rating), presented at the end of each trial, was used throughout the entire experiment.

Stimuli were presented using the IFIS system (MRI Devices, Inc., Milwaukee, WI), a stimulus display and experimental package. Stimuli were displayed through goggles (VisuaStim XGA, Resonance Technologies) placed above the participant's eyes. Responses were recorded by a button glove attached to the participant's right hand and linked to the IFIS system. The E-prime software package (PST, Inc., Pittsburgh, PA), integrated with the IFIS system, was used to conduct the experiment.

fMRI acquisition

Magnetic resonance imaging scanning occurred on a GE 3 T Signa scanner (Excite 2.0, Neuro-optimized gradients; General Electric, Milwaukee, Wisconsin). Head movement was minimized through instructions to the participant and also through custom-fit foam pads that provided comfort and minor immobilization. Ear plugs were provided to reduce scanner noise. Scanning began with the structural acquisition of a standard T1 image (T1-overlay) for anatomic normalization and alignment (repetition time = 2000 ms, echo time = 30 ms, flip angle = 90°, field of view = 220 mm, 40 slices, voxel size 3.4375 × 3.4375 × 2.5 mm^3, matrix 256 × 256, slice thickness 2.5 mm, 0 skip). A T2*-weighted, reverse spiral acquisition sequence (gradient echo, matrix 64 × 64) occurred in the same prescription as the T1-overlay, and 185 volumes were acquired for each session, after discarding 4 initial volumes to permit thermal equilibration of the MRI signal. Seven session runs were obtained. The T2* reverse spiral acquisition sequence was specifically designed to enable good signal recovery in ventral medial frontal regions, where susceptibility artifact often impairs the T2* signal (Noll et al., 1998; Yang et al., 2002). After acquisition of functional volumes, a high-resolution T1 scan was obtained for anatomical normalization (three-dimensional spoiled-gradient echo [SPGR], repetition time = 10.5 ms, echo time = 3.4 ms, flip angle = 25°, field of view = 240 ms, 106 slices, voxel size 0.86 × 0.86 × 1.5, matrix 256 × 256, 1.5 mm slice, 0 skip).

fMRI analyses

Scans were reconstructed and all functional data were subjected to an initial series of preprocessing steps. First, the data were sinc-interpolated in time, slice-by-slice, to correct for the staggered sequence of slice acquisition. Next, a six-parameter, least-squares minimization, motion correction algorithm, using the McFlirt program (Jenkinson and Smith, 2001), was applied to realign all functional data from a given participant to the tenth image acquired during the first run of the scanning session. The data were then automatically thresholded to exclude extra-parenchymal voxels from subsequent analysis, and the scan-wise global signals and power spectra were derived and stored. Subsequent processing and analyses of the images were then conducted using the Statistical Parametric Mapping program (SPM2; Wellcome Institute of Cognitive Neurology, London, United Kingdom) on a MATLAB (The MathWorks INC., Natick, MA) platform. The scans were co-registered with the high-resolution SPGR T1-image. This high-resolution image was then anatomically normalized to the MNI152 template brain, as implemented in the SPM2 package. The resulting transformation parameters were applied to the time series of co-registered, normalized functional volumes. The normalized functional volumes were then smoothed with a 6-mm isotropic Gaussian smoothing kernel. In one participant, this normalization procedure produced a void signal in the orbitofrontal area, a region of interest for the current study. Consequently, this participant's fMRI data, as well as behavioral data from the scans, were excluded in the individual and group level analyses.

In each run, participants typically finished the task before the scanning time in a run had completed. To address this, the extra scan volumes after 4 scan volumes (4 TRs) from the last event trial in each run were removed. Four scan volumes from the last event in the run were included to allow for better modeling of the blood-oxygenated level-dependent (BOLD) response to the last event. Standard neuroimaging methods using the general linear model were used with the first-level (individual) analyses. The BOLD response was modeled with the following regressors of interest: 1) the decision phase, 2) the anticipation phase, 3) regret outcome, 4) disappointment outcome, 5) elation outcome, 6) rejoice outcome, 7) filler outcome, 8) emotion rating, and 9) fixation. The decision phase was modeled from the 500 ms range after the display onset of the gambles to when the participant made a response. The first 500 ms in each trial were excluded to reduce the effects of initial eye fixation to targets. Each regressor epoch was convolved with a canonical hemodynamic response function (HRF).

Three sets of analyses were performed for each participant at the individual level. In the first analysis, outcome trials were categorized according to the four specific emotions of interest: i) regret, ii) disappointment, iii) elation, and iv) rejoice. In the second analysis, the four emotion conditions were categorized as "emotion outcome", and the subjective rating served as a parametric regressor. In the third analysis, we used the "emotion outcome" epoch with a parametric regressor based on the difference between the outcome of the gamble the participant could have received and the outcome the participant actually received in each trial. The individual level analyses provided contrast images that were used for analyzing group effects at a second level.

The second-level random effects analysis used one-sample t-tests on the contrast images obtained from the first-level analyses. This analysis estimates the error variance for each condition of interest across participants by accounting for subject heterogeneity. All contrasts also used the uncorrected threshold, with group effects set at $p<.005$ and cluster extent ≥ 5 voxels. Images were presented with an uncorrected threshold of $p<.005$, cluster extent ≥ 5 voxels.

Results

Behavioral results during the scans

Fig. 1C presents the behavioral data during the fMRI scans. Replicating Experiment 1, participants reported that they wished they had chosen a different gamble more after regret than after disappointment, $t(10)=8.20$, $p<.001$. Also, participants reported a stronger wish to "switch" to a different gamble after experiencing negative emotion outcomes (disappointment and regret) than after experiencing positive emotion outcomes (elation and rejoice), $Ms=25.28$ vs. -8.66, main effect of emotion valence, $F(1,10)=121.32$, $p<.001$. There was also a main effect of feedback on the ratings, $F(1,10)=32.47$, $p<.001$, such that the complete feedback condition (regret and rejoice) received more extreme ratings. Also, there was an interaction effect of valence and feedback on the ratings, $F(1, 10)=58.48$, $p<.001$, with regret trials producing a stronger desire to switch choices than the other three emotions. Participants reported a lower desire to change their choice after experiencing rejoice than after elation, $t(10)=3.44$, $p<.01$. There was no significant decision latency difference between the regret and disappointment conditions. Similar to Experiment 1, participants took longer to decide on the next trial after rejoice than after elation, $t(10)=2.36$, $p<.05$.

fMRI results

Comparison of positive and negative emotion outcomes. To examine activation patterns associated with emotional valence, we combined the two positive emotion conditions and contrasted them to the two negative emotion conditions. Consistent with the neuroanatomy of the reward system and previous neuroimaging work (e.g., Coricelli et al., 2005), the comparison between the emotions induced by winning vs. losing, (rejoice + elation) − (regret + disappointment), revealed greater activation in the sublenticular extended amygdala (SLEA)/ventral striatum, [(12, 6, −15), $Z=4.07$, $k=180$], [(−18, 9, −12), $Z=4.47$, $k=185$]. In addition, this contrast also showed enhanced activation in the medial orbitofrontal cortex [(0, 54, −6), $Z=4.34$, $k=112$] (see Fig. 3).

Overlapping and differential areas of activation for regret and disappointment. We next examined the two positive emotion conditions and the two negative emotion conditions separately. We found no significant activation differences between the two positive emotion conditions (Rejoice>Elation). We focus on the similarity and differences in activation between regret and disappointment conditions. To determine overlapping areas of activation between regret and disappointment, we made independent comparisons of regret and disappointment with fixation as well as conjunction analyses. We found that both regret and disappointment activated the anterior insula and the dorsomedial prefrontal cortex (see Table 1 and Fig. 4), which were significant at both the .005 and .001 criterion levels. Conducting exclusive masking on the regret and disappointment contrasts vs. fixation did not yield any unique areas of activation. Contrasting regret against disappointment outcomes also showed significant activation differences in the right anterior insula, left insula/superior temporal gyrus/inferior temporal gyrus, Brodmann's area 8 (BA8) or superior frontal gyrus, and the lateral orbitofrontal cortex (see Table 1, Fig. 5). The right and left anterior insula activations were also significant at .001 criterion level.

Effect of subjective ratings of counterfactual thinking on the outcome epoch. To examine the association between expressed desire to change choice and brain activation patterns, we analyzed the emotion outcome epochs for all outcome trials with the participants' subjective ratings as a parametric modulator. Activation in the dorsomedial prefrontal cortex, ventromedial prefrontal cortex, and the anterior cingulate during the emotion outcome epoch was associated with a stronger desire to change their choice (Table 2 and Fig. 6A). Additional contrasts using subject ratings as a parametric regressor focusing only on regret and disappointment trials produced similar findings as for all trials.

Effect of objective counterfactual comparison on the outcome epoch. To assess neural activation patterns associated with counterfactual

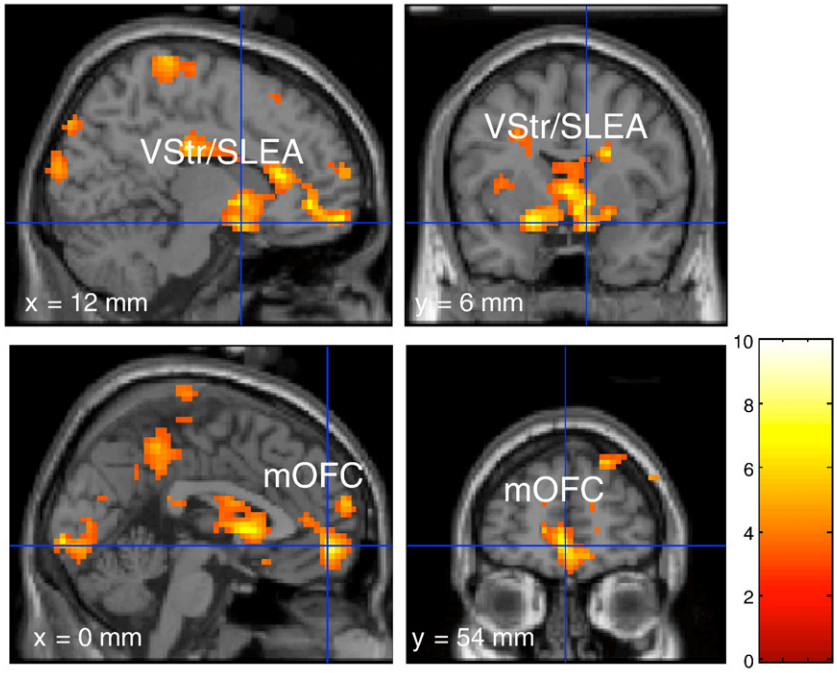

Fig. 3. Activation patterns for positive (rejoice and elation) vs. negative (regret and disappointment) emotion outcomes. Activation patterns in the sublenticular extended amygdala (SLEA) and medial orbitofrontal cortex (mOFC) discriminated positive vs. negative emotion outcomes. Activated voxels are displayed with $p<0.005$ uncorrected, $k\geq5$ voxels threshold.

comparison during the emotion outcome phase, we calculated a “counterfactual index score” for each trial for each participant. Specifically, we examined the counterfactual comparison involved when comparing the unobtained value from the unselected gamble with the obtained value of the selected gamble, based on objective numerical values from the gambles. In the complete feedback (regret and rejoice) trials, the score was a difference between the unobtained value of the unselected gamble and the obtained value of the selected gamble. In the partial feedback (disappointment and elation) trials, the score was the difference between zero and the obtained value of the selected gamble. Zero was the objective default value for the unselected gamble because the participants were unaware of the outcome of the unchosen gamble. The above procedure produced a difference score, with regret trials having the highest score, followed by disappointment, elation, and rejoice. This score was entered as a parametric regressor for the emotion outcome trial epochs. Results show that higher difference score values were associated with activations in the lateral orbitofrontal cortex, dorsolateral prefrontal cortex, and the sublenticular extended amygdala (see Table 2, Fig. 6B). Additional contrasts using the counterfactual scores as a parametric regressor focusing only on regret and disappointment trials produced similar findings as for all trials.

Discussion

In two experiments we compared subjective experience and neurophysiological correlates of regret and disappointment — emotions associated with decision-related loss that differ in their purported attribution and self-blame. Behaviorally, despite identical nominal losses, participants reported greater dislike of their choices and the outcomes of their choices when they experience regret as opposed to disappointment. In contrast to disappointment, participants also decided faster on the subsequent trial after experiencing regret. Neurophysiologically, regret and disappointment activated some shared (overlapping activation) brain regions including anterior insula and the dorsomedial prefrontal cortex. When compared to disappointment, regret enhanced activity in the anterior insula, the lateral orbitofrontal cortex, and the BA8 region (part of dorsomedial prefrontal cortex).

Subjective experience and neural correlates of decision-related loss

Both regret and disappointment led to greater dislike of the outcomes and a stronger desire to change choices. In addition, both emotions shared some overlapping areas of activation — anterior insula and dorsomedial prefrontal cortex (including the anterior cingulate). These findings are expected given that both regret and disappointment are negative emotions associated with decision-related loss. The neural activation patterns for decision-related loss also replicate previous findings. Anterior insula activations are consistent with prior work implicating this region in response to punishing feedback or error signal (Dosenbach et al., 2006; O'Doherty et al., 2003). Dorsomedial prefrontal cortex activations, including the anterior cingulate cortex, have also been associated with response to performance errors (Allman et al., 2005; Cardinal et al., 2002; Dosenbach et al., 2006; Ridderinkhof et al., 2004) and response conflict (Rushworth et al., 2005). In addition, both regions have been implicated in the generation and representation of peripheral autonomic states (for a partial review, see Dolan, 2002) that are likely to accompany externally generated negative emotions.

Negativity dominance and positive emotions

In contrast to the negative emotions associated with decision-related loss, we did not observe differences in neural activation patterns between rejoice and elation (emotions associated with positive decision outcomes). This null activation finding in the domain of positive emotions occurred in the context of statistically significant subjective and behavioral differences between elation and rejoice, i.e., greater liking of choice or outcome and longer decision times on the next trial associated with rejoice than with elation. A growing literature on negativity dominance may explain the lack of activation differences in the positive emotions. It is argued that the negative domain is experienced with greater magnitude and sensitivity than the positive domain (Baumeister et al., 2001; Rozin and Royman,

Table 1
Activation of regret and disappointment relative to fixation, and activation of regret relative to disappointment.

Region	x, y, z[a]	Z[b]	k[c]
Regret>fixation			
R, Anterior insula (BA 13)	54, −12, 15	4.44+	1016
L, Anterior insula (BA 13)	−51, 9, −6	3.90+	*
Dorsomedial prefrontal cortex superior frontal Gyrus (BA 8)/cingulate gyrus (BA 24)	3, 9, 36	4.06+	320
R, Precuneus (BA 7)	6, −66, 45	4.01+	135
L, Precuneus (BA 7)	−30, −75, 54	4.14	85
L, Precentral gyrus/middle frontal gyrus (BA 6)	−48, 3, 54	3.84+	151
R, Postcentral gyrus (BA 2)	51, −30, 57	4.62	53
Disappointment>fixation			
R, Anterior insula (BA 13)	48, −12, 12	4.31+	151
L, Anterior insula (BA 13)	−30, 3, 9	4.03+	170
Dorsomedial prefrontal cortex superior frontal Gyrus (BA 8)/cingulate gyrus (BA 24)	3, 18, 48	4.13+	533
R, Precuneus (BA 7)	6, −66, 42	5.33+	386
L, Precuneus (BA 7)	−27, −72, 48	4.03+	260
L, Precentral gyrus/middle frontal gyrus (BA 6)	−51, 3, 54	4.55+	470
R, Postcentral gyrus (BA 2)	54, −30, 57	4.69+	128
Regret>disappointment			
R, Anterior insula (BA 13)	39, 12, 21	4.42+	342
L, Insula (BA 13)/inferior frontal gyrus (BA 47)	−48, 21, −12	3.08+	22
R, Superior frontal gyrus (BA 8)	18, 45, 48	**	
L, Middle frontal gyrus (BA 8)	−27, 36, 42	3.25	21
Lateral orbitofrontal cortex superior frontal gyrus (BA 11)	24, 54, −12	3.05	9
Occipital gyrus (BA 19)	30, −84, 30	4.53+	96

*Part of superior temporal gyrus cluster.
**Part of right anterior insula cluster.
[a] Stereotactic coordinates from MNI atlas, in mm., left/right (x), anterior/posterior (y), and superior/inferior (z), respectively, R = right, L = left.
[b] Z score, significant at uncorrected p of 0.005, threshold ≥5 voxels.
[c] Spatial extent in cluster size, threshold ≥5 voxels.
+ Z score, significant at uncorrected p of 0.001, threshold ≥5 voxels.

2001). If the proposed negativity dominance is rooted in functional neuroanatomical differences, one would expect the brain to be more sensitive to differences in emotions in the negative domain than to differences in emotions in the positive domain, and potentially leading to lack of activation differences between the two positive emotions (or at least lower signal strength in the positive emotions than in the negative emotions). This idea should be tested in future work.

Subjective experience and neural correlates of regret versus disappointment

We observed behavioral response differences between regret and disappointment. Despite identical nominal losses, the current studies demonstrated that regret led to a greater dislike of the outcome, in contrast to earlier reports (e.g., Mellers et al., 1999) that failed to find differences. Moreover, we also found that regret induced a stronger desire to change previous choice than disappointment, consistent with other prior work (Zeelenberg et al., 1998a, 1998b). Regret also led to faster subsequent decisions than disappointment, potentially related to the stronger desire to correct a mistake.

In addition to the behavioral differences between regret and disappointment, there were also distinguishable neural activation patterns between regret and disappointment. Enhanced activation in the anterior insula, BA 8, and the lateral orbitofrontal cortex were observed when comparing regret to disappointment. Medial prefrontal cortex, including the enhanced activity in BA 8 when contrasting regret with disappointment, has been associated previously with the reappraisal of negative emotion states (see Ochsner and Gross, 2005). It is possible that regret involves more reflective reappraising of the decision process or outcome than does disappointment. [The activation peak in BA 8 is more anterior than the typical region associated with the frontal eye fields, which is activated during saccadic eye movements (Luna et al., 1998; Richter et al., 2005)].

There was also greater activation in the lateral orbitofrontal cortex when comparing regret with disappointment. This is a novel finding as previous research (Coricelli et al., 2005) on regret and disappointment failed to demonstrate enhanced activity in this region. Other prior work has shown that increases in punishment or losing magnify activity in the lateral orbitofrontal cortex (O'Doherty et al., 2001). The orbitofrontal cortex has been shown to have an important role in reversal learning, which involves reversing stimulus–reinforcement associations when the associations no longer hold (Hornak et al., 2004). Together with the dorsomedial prefrontal cortex, it also has been associated with response inhibition, the ability to override the execution of an action, emotion, or thought (Matthews et al., 2005). Thus, it is possible that activation of lateral orbitofrontal cortex in our studies reflect regret-related reversal learning and response inhibition processes.

Greater insula activity during regret than disappointment did not correlate with the magnitude of subjective loss, suggesting that this difference in anterior insula activation is not fully accounted for by the differences in the magnitude of emotional experience in our subjects. The activation of anterior insula and BA 8, an area within the dorsomedial prefrontal cortex, may potentially be related to enhanced self-relatedness in regret than in disappointment. Whereas both disappointment and regret are emotions associated with decision-related loss, regret is expected to differ from disappointment on aspects of attribution and self-blame. Both anterior insula (Craig, 2009; Fink et al., 1996) and dorsomedial prefrontal cortex (Chua et al., 2009; Phan et al., 2004) have been shown to be activated during self-related processing.

Subjective desire to change choice

The role of self-relatedness is also demonstrated when we correlated brain activity during emotion outcome with subjective desire to change choice. The desire to change choice was associated with enhanced activity in the dorsomedial prefrontal cortex, the anterior cingulate cortex, and the ventromedial prefrontal cortex. Activations in the medial prefrontal cortex have been implicated in self-referential reflective activities (e.g., Chua et al., 2009; D'Argembeau et al., 2005; Kelly et al., 2002; Ochsner et al., 2005; Phan et al., 2004), suggesting again the potential association between self-referential reflective thinking and a stronger desire to change a choice, which was strongest during regret.

Comparison with prior neuroscience work on regret and disappointment

We did not find that regret activates medial OFC as reported by the study of Coricelli et al. (2005). One noteworthy difference between the two studies was that our findings were based primarily with contrasts of regret and disappointment against each other and against a control condition (fixation), whereas the Coricelli et al. (2005) study found medial OFC activation by using the outcome of the unselected gamble as a parametric regressor for regret and rejoice trials in the complete feedback condition. In this case, they found that medial OFC activated more with regret and deactivated more in rejoice trials. Another difference between the two studies was that our emotion trials were intermixed within each block, unlike previous studies (Camille et al., 2004; Coricelli et al., 2005; Coricelli et al., 2007; Mellers et al., 1999) where partial feedback trials (disappointment and elation trials) were grouped in separate blocks from complete feedback trials (regret and rejoice trials). In that scenario, when deciding between the gambles, people would always expect only the outcome of their chosen gamble in the block of partial feedback trials and people would always expect both outcomes of chosen and unchosen gambles in the block of complete feedback trials. In our task, when deciding, the participant does not know whether they will see their own outcome alone or they will receive complete feedback.

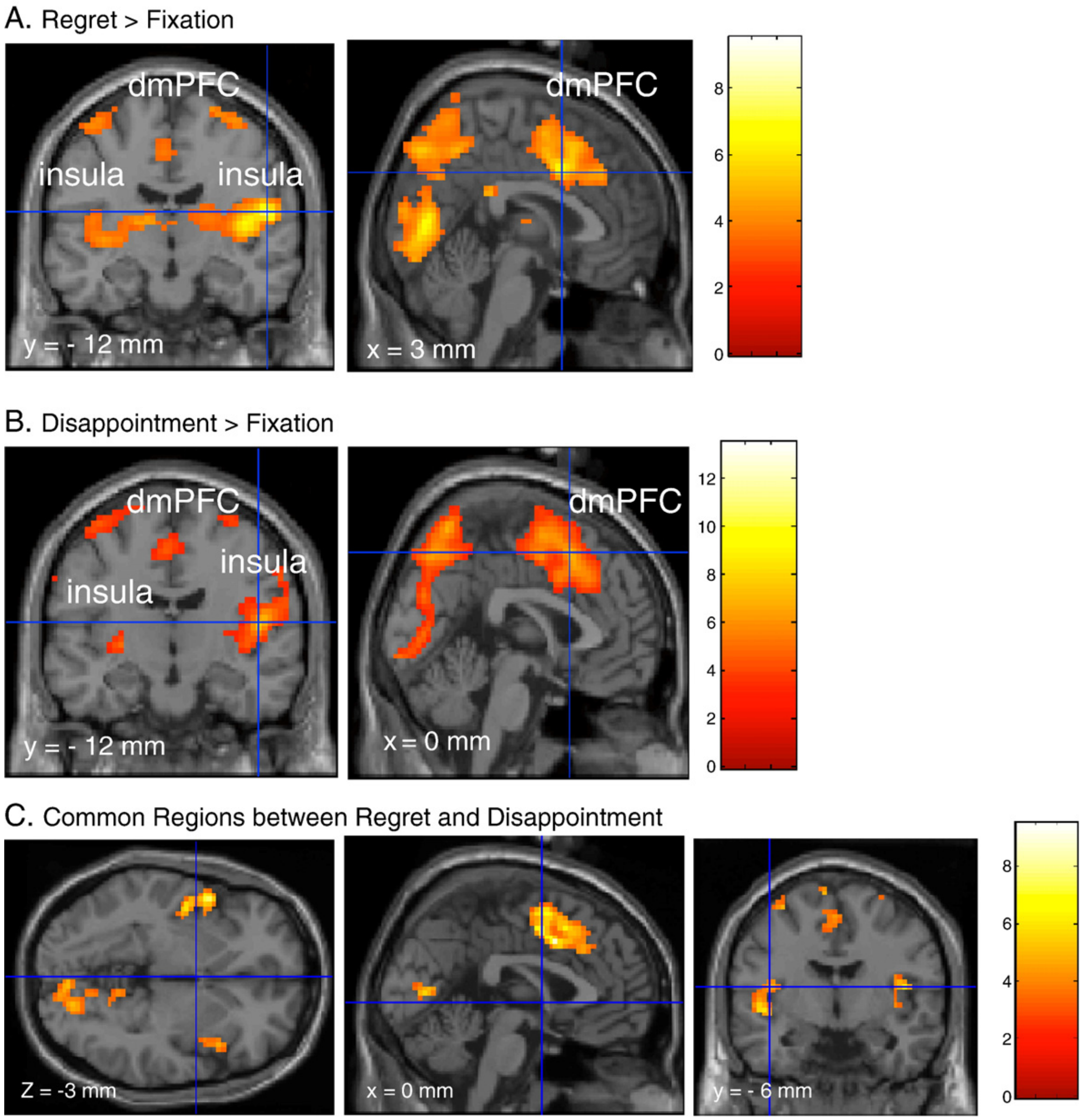

Fig. 4. Areas of activation for regret and disappointment, relative to fixation, as well as common areas of activation for both emotions. Both regret and disappointment activated the insula and dorsomedial prefrontal cortex relative to fixation. Activated voxels are displayed with $p<0.005$ uncorrected, $k \geq 5$ voxels threshold.

Counterfactual comparisons and its role on emotions

We also examined the neural activation patterns involved in counterfactual thinking. We observed that comparing what you could have obtained with what you actually received was correlated with activation in the lateral orbitofrontal cortex, dorsolateral prefrontal cortex (DLPFC), and the SLEA/ventral striatum. This is consistent with previous work that associated the lateral orbitofrontal cortex

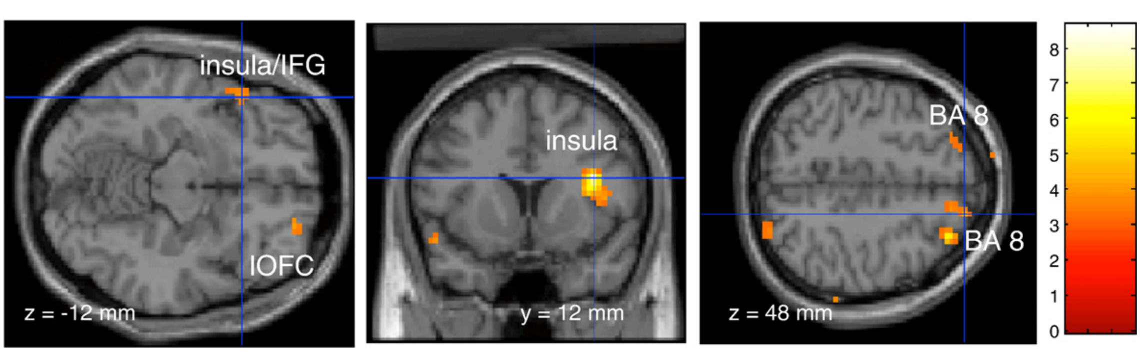

Fig. 5. Differential activation patterns contrasting regret and disappointment. Activity in the anterior insula, Brodmann's area 8, and the lateral orbitofrontal cortex discriminated regret from disappointment outcomes. Activated voxels are displayed with $p<0.005$ uncorrected, $k \geq 5$ voxels threshold.

Table 2
Activation during the emotion outcome epoch comparing (a) the influence of the subjective desire to change choice and (b) the influence of the objective counterfactual comparison score.

Region	(x, y, z)[a]	Z[b]	k[c]
(a) Influence of the subjective emotional rating on the emotion outcome epoch			
Medial frontal gyrus (BA 9)	−12, 30, 36	4.07	119
Superior frontal gyrus (BA 9)	18, 54, 30	4.00	76
Anterior cingulate (BA24)	9, 27,24	3.90	30
Middle frontal gyrus (BA 10)	−24, 54, 21	3.38	17
(b) Influence of the difference score on the emotion outcome epoch			
L, Middle frontal gyrus (BA 11)	−18, 42, −15	3.70	30
R, Middle frontal gyrus (BA 11)	27, 45, −9	3.31	10
Inferior frontal gyrus (BA 45)	−51, 12, 24	3.55	113
R, Sublenticular extended amygdala	18, 3, −6	3.17	8
L, Sublenticular extended amygdala	−12, 0, −9	3.07	15
Substantia nigra	6, −15, −18	3.76	62
Middle frontal gyrus (BA 10)	−45, −51, 9	3.69	37
L, Middle temporal gyrus (BA 37)	−60, −48. −12	3.59	141
R, Inferior temporal gyrus (BA 19)	51, −63, −6	3.48	38

[a] Stereotactic coordinates from MNI atlas, in mm., left/right (x), anterior/posterior (y), and superior/inferior (z), respectively, R = right, L = left.
[b] Z score, significant at uncorrected p of 0.005.
[c] Spatial extent in cluster size, threshold ≥5 voxels.

(O'Doherty et al., 2003) and SLEA/ventral striatum (Pagnoni et al., 2002) with processing the difference between expected and observed outcomes.

Limitations

A number of limitations have to be considered when evaluating the results of these experiments. First, it is possible that some participants may have experienced some regret during the disappointment trials. If this were true, we likely underestimated the differences between the two emotions and the differences we found from the direct comparison between the two emotions might have been even stronger or more pronounced. On the other hand, an inability to completely separate the two emotions could have contributed to the "overlap" in activation patterns we reported. Second, with respect to the technical aspects of the paradigm, in the complete feedback condition, the pointer spun for 2 s for the unchosen gamble and 3 s for the chosen gamble, whereas the pointer spun 3 s for the chosen gamble in the partial feedback condition. We do not have data suggesting that this has behavioral and neural effects on the outcome, i.e., regret and disappointment. Third, the feedback leading to regret and disappointment conditions differed with amount of details presented. It is unlikely however that greater activity in anterior insula, BA 8 and lateral orbitofrontal cortex for regret vs. disappointment could be explained by the simple differences in amount of information displayed on the screen during complete feedback vs. a partial feedback. If complete feedback led to increased signal in anterior insula, BA 8 and lateral orbitofrontal cortex compared to partial feedback, one would expect the same areas to be differentially activated when contrasting rejoice and elation. However, contrasting rejoice with elation did not yield differences in activation in the aforementioned areas. Lastly, future studies should further examine whether the increased activation in anterior insula and BA 8 in regret versus disappointment reflects greater self-related processing. In Experiments 1 and 2, the subjective ratings used did not completely tease apart liking of outcomes or desire to change choice from self-relatedness. Additional subjective parameters directly measuring self-relatedness may be needed in future studies.

Conclusions

Understanding behavioral and neural correlates of regret and disappointment is important in elucidating the roles of emotions in

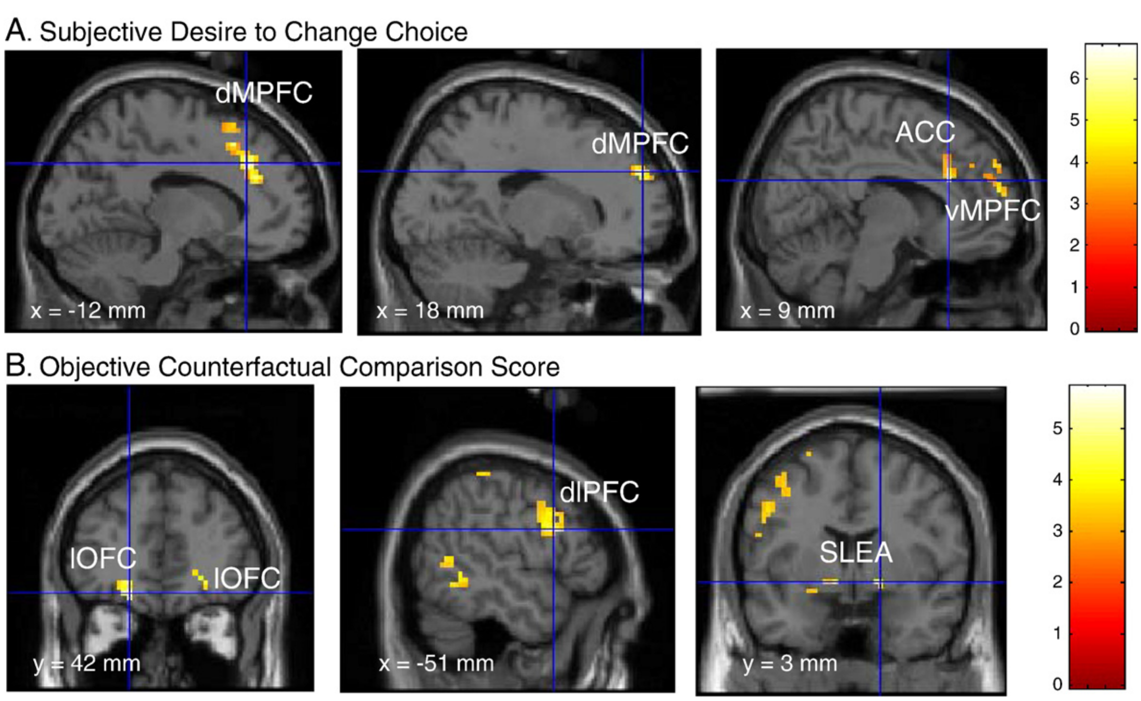

Fig. 6. (A) Activity during the emotional outcome as modulated by the ratings of how much subjects wished they could change their choices. Greater desire to change choice was correlated with enhanced activity in the dorsomedial prefrontal cortex, ventromedial prefrontal cortex, and the anterior cingulate cortex. (B) The effect of the difference between the unobtained outcome and obtained outcome on the activation patterns during the emotional outcome. For the complete feedback (regret and rejoice) trials, the score was calculated as the difference between the unobtained value of the unchosen gamble and the obtained value of the chosen gamble. For the partial feedback (disappointment and elation) trials, the score was the difference between zero and the obtained value of the selected gamble. Regret yielded the highest score, followed by disappointment, elation, and rejoice. The difference score modulated activity in the lateralorbitofrontal cortex (lOFC), dorsolateral prefrontal cortex (DLPFC), and sublenticular extended amygdala (SLEA) during the emotional outcome. Activated voxels are displayed with $p<0.005$ uncorrected, $k \geq 5$ voxels threshold.

decision making and has implications for understanding psychiatric problems that involve excessive regret. The present studies examined several aspects of the decision process, including the counterfactual thought processes involved during the outcome and the subjective experience and associated neural activation patterns of the emotions, albeit preliminarily. Previous behavioral research (Zeelenberg et al., 1998a, 1998b) indicates that regret and disappointment are subjectively different. The present study suggests, using behavioral and imaging data, that regret produces a stronger desire to change choice and a stronger negative affective reaction to the outcome of their choice. The studies show that whereas regret and disappointment share some areas of activation (anterior insula and medial prefrontal regions), regret activated them more, including enhanced activation in the lateral orbitofrontal cortex.

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