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THE NEURAL BASIS OF REGRET AND RELIEF DURING A SEQUENTIAL RISK-TAKING TASK

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Abstract—Regret and relief are associated with counterfactual thinking and are sensitive to various social contexts. In the present fMRI study, we investigated the neural basis for regret and relief and how social context (following vs. not following advice) modulates them by employing a sequential risk-taking task. Participants were asked to open a series of boxes consecutively until they decided to stop. Each box contained a reward (gold), except for one that contained an adverse stimulus (devil), which caused the participant to lose all the gold collected in that trial. Before each trial, participants received advice about when to stop, which they then chose to follow or not. Behaviorally, subjective regret and relief were primarily dependent on the number of missed chances and the trade-off between obtained gains and missed chances, respectively. Participants felt less regret when they chose not to follow the advice than when they did. At the neural level, striatum, vmPFC/mOFC, and vACC activations were associated with greater relief. Meanwhile, dmPFC and left superior temporal gyrus were associated with greater regret. Additionally, dACC showed stronger activation in the Not-Follow context than the Follow context.

Key words: decision-making, fMRI, regret, relief, risk taking, reward.

INTRODUCTION

Individuals make countless decisions in everyday life. Often by selecting one option, a person must also reject the alternatives. When the outcomes of these alternative options become known, this information can modulate the evaluation of the obtained outcome, a phenomenon known as counterfactual thinking (Roese, 1994, 1997; Zeelenberg et al., 1998). Counterfactual thinking requires one to mentally juxtapose the representations of ''what might have been" and what has actually occurred (Bell, 1982; Zeelenberg, 1999; Zeelenberg and Pieters, 1999). Individuals experience regret if the actual outcome of their choice is worse than that of the rejected alternatives (Bell, 1982; Markman et al., 1993; Connolly and Zeelenberg, 2002). Besides regret, counterfactual thinking can sometimes instead induce relief. Contrary to regret, relief results from a comparison between reality and a more negative, fictive reality (Connolly and Zeelenberg, 2002; Guttentag and Ferrell, 2004; Coricelli and Rustichini, 2010). Both regret (due to upward counterfactual thinking) and relief (due to downward counterfactual thinking) are subjective feelings that result from counterfactual thinking (Kelsey and Schepanski, 1991; Boles and Messick, 1995; Mellers, 2000).

A typical task used in investigating the emotion of regret and relief is 'wheels of fortune' (Camille et al., 2004; Coricelli et al., 2005; Liu, 2007; Chua et al., 2009), in which participants are asked to make a choice between two alternatives. After the decision, the outcomes of both selected and unselected alternatives are presented. In these studies, participants have been shown to experience regret when they win less or lose more than the unselected alternative; on the contrary, they experience relief when they win more or lose less. Neuroimaging results have shown that the frontal gyrus is involved in the experience of regret and its involvement has usually been interpreted as being associated with counterfactual thinking (Camille et al., 2004; Coricelli et al., 2005; Chua et al., 2009). Moreover, several studies have shown reward-related brain regions, like the

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Abbreviations: EPI, echo-planar imaging; mOFC, medial orbitofrontal cortex; RGP, real gain-percentage; vmPFC, ventromedial prefrontal cortex.

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striatum, to be involved in the experience of relief (Delgado et al., 2000; Hassani et al., 2001; Elliott, 2003; Chandrasekhar et al., 2008; Xue et al., 2009).

However, besides simple, stand-alone decisions, people are frequently required to make many sequential risk decisions, such as deciding when to sell stocks. During these sequential risky decisions and the resulting outcomes, people may experience more complex feelings of regret and relief. To address this issue, Brassen and colleagues (2012) employed a modified version of the sequential risk-taking task that induced the feeling of regret. During the task, participants were asked to open a series of boxes consecutively and decide when to stop. All except for one box contained a reward (gold); the remaining box contained an adverse stimulus (devil) that caused participants to lose all the gold that had been collected in that trial. When participants decided to stop, the position of the devil was shown, revealing the number of collected gains and missed chances. Participants were paid based on the amount of gold they had at the end of the task. Brassen and colleagues (2012) found that self-reported regret was positively correlated with the magnitude of the reward that participants missed out on obtaining. Moreover, the striatum was involved in optimal outcome processing. In addition, both larger missed chances and stronger feelings of regret predicted more subsequent risk taking. However, in this task, participants' emotional states might be also affected by the actual rewards obtained. For example, in the case of missing out on two boxes of gold (missed chance), participants might have different emotional reactions if they had successfully collected either one or five boxes of gold before stopping. In the former case, a participant may indeed experience regret whereas in the latter case, a participant may experience less regret and even possibly some relief. Based on this possibility, we extended the scale used for rating subjective emotions. We expected that the emotional ratings might be modulated by the trade-off between the obtained gain and missed chance, and we introduced a combined index, called real gain-percentage (RGP), to the present study indicating this trade-off. The RGP was defined as the ratio of the obtained gain and the largest possible gain (that is, the total number of boxes before the devil, or the sum of the obtained gain and the missed chance) in a given trial.

We predicted that participants might actually experience relief on some missed chance trials. By considering RGP, there might be four different possible conditions: (i) $\text{regret}_{\text{Miss}}$ condition, when participants miss some chances with a relatively smaller RGP, (ii) $\text{relief}_{\text{Miss}}$ condition, when participants miss some chances with a relatively larger RGP, (iii) Optimum condition, when participants get the largest possible gain (RGP equals 1), and (iv) Devil condition, when participants unpack the devil and get nothing (RGP equals 0). We predicted that reward-related brain regions, like striatum (Connolly and Zeelenberg, 2002; Chandrasekhar et al., 2008; Brassen et al., 2012; Guttentag and Ferrell, 2004; Coricelli and Rustichini, 2010), would be involved in relief processing. Moreover, we predicted that the frontal gyrus, which has previously been associated with negative emotion and negative outcome feedback (Chua et al., 2009; Ridderinkhof et al., 2004; Dosenbach et al., 2006; Liu, 2007), would be involved in regret processing.

In addition, past research has revealed that regret is modulated by social contexts, such as advice-taking. For example, several studies have revealed that whether or not a person took the advice of others affected regret. Crawford and colleagues (2002) found people experienced greater regret after following others' advice. Similarly, another study showed involuntarily childless women were more likely to have child-related regret than voluntarily childless women (Jeffries and Konnert, 2002). Thus, by applying the modified version of the sequential risk-taking task (Büchel et al., 2011; Brassen et al., 2012), we tried to investigate the effect of social context (following vs. not following advice) on regret and relief.

EXPERIMENTAL PROCEDURES

Participants

Eighteen right-handed participants (ten female, aged from 23 to 31, $M = 24.61$, $SD = 2.09$) from the university community with normal or corrected-to-normal vision participated in this experiment. None of the participants had abnormal neurological history. All gave informed consent before scanning. This study was approved by the Ethics Committee of East China Normal University.

Procedure

Before scanning, participants were told that they would play a sequential decision task while undergoing fMRI scanning. Before every trial, they would be presented with the advice (‘‘stop earlier" or ‘‘stop later"), and they were told that each piece of advice was proposed by a different ‘‘average" person (a person who was unknown to them and had no interaction with them). By doing so, we could avoid participants from relating the advisors to different stereotypes. Participants were also told that whether or not the advice would be helpful was unsure. Once they decided to follow or not to follow the advice by pressing corresponding buttons (‘‘1" for ‘‘Follow", ‘‘2" for ‘‘Not-Follow"), participants were required to abide by the rules (i.e. ‘‘stop earlier" meant stopping at the first three boxes, ‘‘stop later" meant stopping at the last five boxes). That is, if the advice was to ‘‘stop earlier", participants were instructed to stop within the first three boxes if they chose to follow the advice or to stop within the last five boxes if they chose not to follow the advice. Participants were also informed that the payment for their participation would be affected by their gains from the task.

Participants completed 90 trials in the scanner. On each trial, they first decided whether they would follow the advice within 2500 ms. Then an array of eight boxes was presented, where seven boxes contained gold coins and one box contained a devil. The position of the devil was set randomly on each trial leading to no significant autocorrelation. Boxes were opened from left to right. At any stage, participants had 2000 ms to either open the next box or stop and collect the gains acquired so far in that trial by key-press. Opening the box with the devil ended the current trial and all gains from that trial were lost. A jittered interval (ranging from 1800 to 2250 ms) was presented after the participant decided to stop or after unpacking the devil. Next, the outcome was presented for 3000 ms and highlighted on the screen by a cyan square (in the case of stopping and collecting the gains) or a red square (in the case of unpacking the devil and losing the gains in that trial). The outcome screen also revealed the actual position of the devil, thus informing participants about how many golds they had gained and how many they had missed at the same time. Finally, an additional jittered intertrial interval (ranging from 1500 ms to 15500 ms) was introduced. Fig. 1 displays two of the possible outcome conditions for a trial.

After scanning, participants were presented with their choices and results from the task completed inside the scanner and were asked to rate how they felt for each trial on a 9-point scale from extreme regret (defined as -4) to extreme relief (defined as 4).

fMRI data acquisition

Scanning was carried out on a 3T Siemens Trio system at the Functional MRI Lab (East China Normal University, Shanghai). For functional images, 35 slices were acquired using a gradient-echo echo-planar imaging (EPI) sequence (TR = 2200 ms, TE = 30 ms, FOV 10 = 220 mm, matrix size = 64×64, slice thickness = 3 mm, gap = 0.3 mm). Before the functional run, a high-resolution structural image was acquired using a T1-weighted, multiplanar reconstruction (MPR) sequence (TR = 1900 ms, TE = 3.42 ms, 192 slices, slice thickness = 1 mm, FOV = 256 mm, matrix size = 256×256).

Data pre-processing and statistical analyses were performed with Statistical Parametric Mapping (SPM8, Wellcome Department of Cognitive Neurology, London). The functional images were corrected for the delay in slice acquisition and were realigned to the first image to correct for interscan head movements. The individual T1-weighted, 3D structural image was co-registered to the mean EPI image generated after realignment. The co-registered structural image was then segmented into gray matter (GM), white matter (WM) and cerebrospinal fluid (CSF) using a unified segmentation algorithm (Ashburner and Friston, 2005). The functional images after slice timing and realignment procedures were spatially normalized to the Montreal Neurological Institute (MNI) space (resampled to $2 * 2 * 2\ mm^3$) using the normalization parameters estimated during unified segmentation and then spatially smoothed with a Gaussian kernel of 8 mm full-width half-maximum (FWHM).

fMRI data analysis

We first conducted the general linear model to investigate the effect of outcome condition (Optimum, Miss, and Devil) (see Brassen et al., 2012). At the first-level analyses, three types of outcomes were defined. (i) Optimum, trials in which participants got the largest possible gain (zero missed chances), (ii) Miss, trials in which participants missed some chances, and (iii) Devil, trials in which participants lost the golds collected in that trial (unpacked the devil). A general linear model analysis created three contrast images for each participant summarizing differences of interest. The three first-level contrast images from each participant were then analyzed at the second level employing a random-effects model (flexible factorial design in SPM8).

In order to differentiate moods (regret and relief) felt when encountering a missed chance, and to further explore how regret and relief might dissociate on different levels, we then focused on the interaction between Mood (regret and relief) and Mood Level (high vs. low) in missed chance (Miss) trials. Another general linear model was conducted. At the first-level analyses, four types of conditions (High Relief, Low Relief, High Regret and Low Regret) were defined: (i) High relief, trials in which participants missed some chances and the emotional ratings were 4 or 3, (ii) Low relief, trials in which participants missed some chances and the emotional ratings were 2 or 1, (iii) Low regret, trials in which participants missed some chances and the emotional ratings were -1 or -2 and (iv) High regret, trials in which participants missed some chances and the emotional ratings were -3 or -4. Additional covariates of no interest were created for gain trials in which the emotional ratings were zero. A general linear model analysis created four contrast images for each participant summarizing differences of interest. The four first-level contrast images from each participant were then analyzed at the second level employing a random-effects model (flexible factorial design in SPM8).

Importantly, additional parametric analyses were preformed to assess how brain activities were modulated by the levels of emotional ratings in gain trials (trials in which participants did not unpack the devil). Two types of conditions were defined, (i) $Relief_{Gain}$, trials in which participants collected golds and emotional ratings were greater than zero, and (ii) $Regret_{Gain}$, trials in which participants collected golds and emotional ratings were less than zero. Additional covariates of no interest were created for trials in which participants unpacked the devil, or felt neither regret nor relief (when emotional ratings equaled to zero). Specifically, emotional ratings were used as the parametric regressors in $Relief_{Gain}$ and $Regret_{Gain}$ conditions respectively and the resulting subject-specific estimates of the parametric regressors at each voxel were then entered into a second-level one sample *t*-test.

Last, we conducted the general linear model to investigate how following advice affected the neural responses to the Outcome (Optimum, Miss, and Devil). At the first-level analyses, six types of conditions were defined according to Context (Follow advice vs. Not-Follow advice) and Outcome (Optimum, Miss, and Devil), (i) Follow_devil, trials in which participants followed the advice and unpacked the devil, (ii) Follow_Miss, trials in which participants followed the

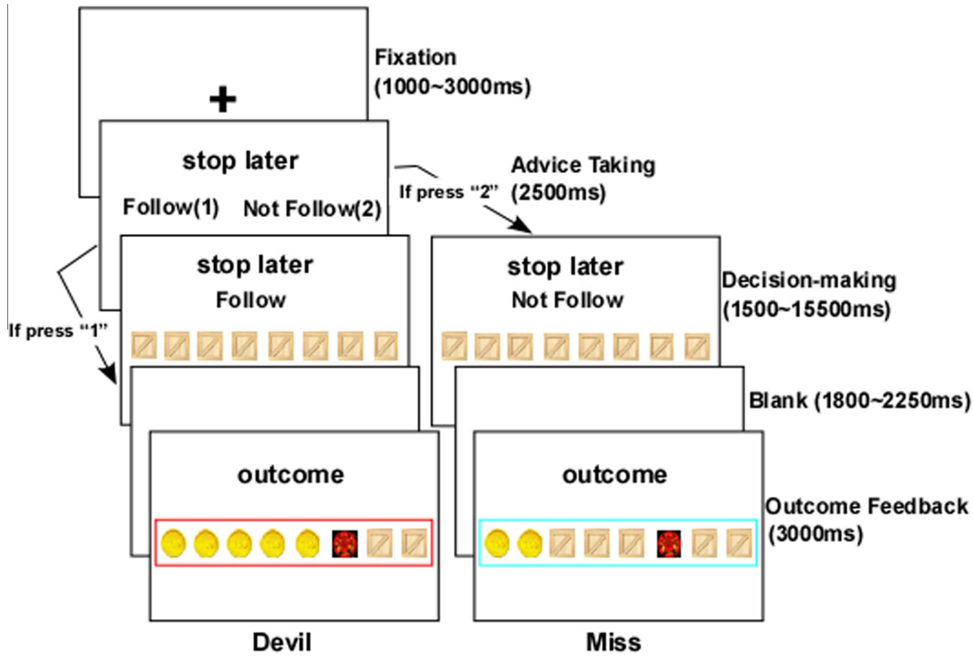

Fig. 1. One possible condition was displayed when participants play the task undergoing fMRI scanning. The advice is 'stop later', if participants selected 'Follow', they were required to abide by the rules (stop at the last five boxes). In the example, the participant has unpacked the devil and the outcome was Devil (lose the five golds collected in that trial). If participants selected 'Not Follow', they were required to stop earlier (i.e., stop at the first three boxes). In the example, the participant has stopped at the second box and the outcome was Miss (miss three golds and gain two golds).

advice and missed some chances, (iii) Follow_Optimum, trials in which participants followed the advice and got the largest possible gain, (iv) Not-Follow_devil, trials in which participants did not follow the advice and unpacked the devil, (v) Not-Follow_Miss, trials in which participants did not follow the advice and missed some chances and (vi) Not-Follow_Optimum, trials in which participants did not follow the advice and got the largest possible gain. A general linear model analysis created six contrast images for each participant summarizing differences of interest. The six first-level contrast images from each participant were then analyzed at the second level employing a random-effects model (flexible factorial design in SPM8).

For all analyses, at the first level, all the conditions were time-locked to the presentation of the outcome of final decision with a duration of 3 s, convolved with a canonical hemodynamic response function (HRF). Additional covariates of no interest were created for movement-related variance and decision-making phase. High-pass temporal filtering with a cutoff of 128 s was also applied in the models. A cluster-level threshold of $p < .05$ (FWE) and a voxel-level threshold of $p < .001$ (uncorrected) were used to define activations.

RESULTS

Behavioral results

Before data analysis, we checked whether participants followed their task instruction about advice-taking. Specifically, we confirmed that all the participants stopped at the first three boxes when they decided to "stop earlier", and stopped at the later five boxes when they chose to "stop later".

First, to analyze the behavioral data, the relationships between participants' emotional ratings and RGP in Follow and Not-Follow contexts were described (Fig. 2A). This showed that in both the Follow and Not-Follow contexts, the tipping-point between reporting regret versus relief was approximately a RGP of 3/5. Essentially, participants tended to feel relief if the RGP was more than 3/5, otherwise, they felt regret. Moreover, to test which was the greatest contributor to emotional ratings in the $\text{Relief}_{\text{Gain}}$ or $\text{Regret}_{\text{Gain}}$ conditions, a series of simple regression analyses based on emotional ratings for $\text{Relief}_{\text{Gain}}$ or $\text{Regret}_{\text{Gain}}$ trials of each participant were performed, in which we defined either obtained gain, missed chance, or RGP as the sole predictor. The R-squared of each simple regression model was calculated. In the $\text{Regret}_{\text{Gain}}$ condition, paired *t*-tests showed the R-squared of missed chance was significantly larger than that of RGP and the R-squared of RGP was significantly larger than that of real gain ($ts < 3.16$, $ps < .01$ with sequential Bonferroni correction). However, in the $\text{Relief}_{\text{Gain}}$ condition, the results showed the R-squared of RGP was significantly larger than that of missed chance and the R-squared of missed chance was significantly larger than that of obtained gain ($ts < 3.06$, $ps < .01$ with sequential Bonferroni correction). The results revealed that the variation of relief could be best explained by the RGP, while the variation of regret was best explained by the missed chance (Table 1).

Then, to investigate how participants' emotional ratings in the current trial predict their behavioral

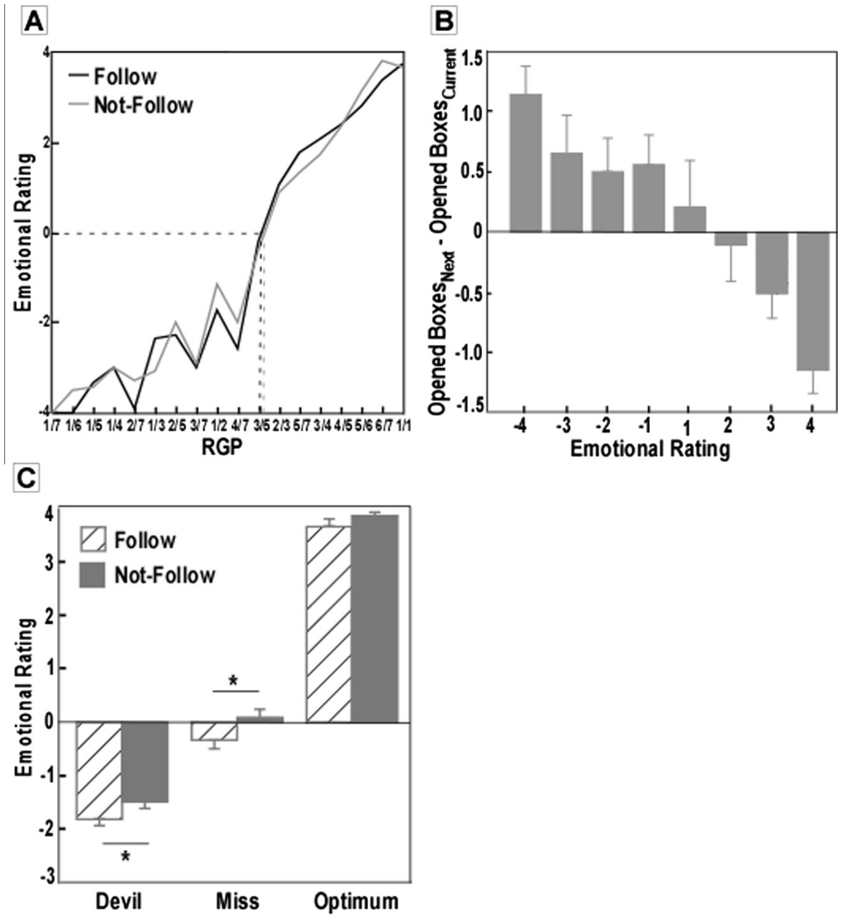

Fig. 2. Behavioral results. (A) The relationship between participants' emotional ratings and RGP in the Follow and Not Follow conditions. Results revealed that in both the Follow context and Not-Follow context, the tipping-point between reporting regret versus relief was approximately a RGP of 3/5. (B) The relationship between emotional ratings in the current trial and behavioral change between the current trial and the next (Opened $\text{Boxes}_{\text{Next}} - \text{Opened Boxes}_{\text{Current}}$) in Gain_Gain condition. (C) Emotional ratings are plotted as a function of 2 Context (Follow advice vs. Not-Follow advice) $\times$ 3 Outcome (Optimum, Miss, and Devil). Repeated measures ANOVA on emotional ratings showed significant main effects of Context and Outcome (both *Fs* < 560.9, both *ps* < .01). No significant interaction was found ($F(2,34) = 1.25$, $p > .05$). Error bars indicate s.e.m.

Table 1. Participants' R-squared (%) of simple regression models (mean ± standard deviation). Obtained gain, missed chance, and RGP were defined as independent variables for emotional ratings in $\text{Relief}_{\text{Gain}}$ and $\text{Regret}_{\text{Gain}}$ conditions, respectively

Condition	R-squared (%)		
	Obtained gain	Missed chance	RGP
$\text{Relief}_{\text{Gain}}$	14.24 ± 13.87	62.37 ± 15.48	71.81 ± 9.23
$\text{Regret}_{\text{Gain}}$	17.33 ± 15.56	70.63 ± 11.90	61.96 ± 16.24

changes in the next one in Gain_Gain condition (trials in which participants did not unpack the devil (i.e. gain, collected golds) in both the current and the next trials), we plotted in Fig. 2B the relationship between emotional ratings in the current trial and behavioral change between the current trial and the next (defined as the difference in numbers of boxes being opened between two successive trials, i.e. Opened $\text{Boxes}_{\text{Next}} - \text{Opened Boxes}_{\text{Current}}$). This analysis showed that if participants rated a lower-than-zero emotional rating (i.e. felt regret) in the current trial, they tended to open more boxes (get more golds) in the next trial than they did in the current trial. And contrarily, if participants rated a higher-than-zero emotional rating (i.e. felt relief) in the current trial, they tended to open less boxes (get less golds) in the next trial than they did in the current trial. We conducted two simple regression analyses in the relief condition and regret condition, respectively. Emotional ratings were defined as the independent variable, and inter-trial behavioral change (Opened $\text{Boxes}_{\text{Next}} - \text{Opened Boxes}_{\text{Current}}$) was defined as the dependent variable. The results showed a significant regression coefficient in relief condition ($\beta = -0.38$, $t = -4.32$), however, no significant coefficient was found in regret condition ($\beta = -0.16$, $t = -1.30$).

Finally, to investigate how advice-following affected the emotional ratings of outcomes. A 2 (Context: Follow advice vs. Not-Follow advice) * 3 (Outcome: Optimum, Miss, and Devil) repeated measures ANOVA on emotional ratings revealed significant main effects of Context and Outcome (both *Fs* < 560.9, both *ps* < .01), indicating higher emotional ratings in the Not-Follow context than in the Follow context. No significant interaction was found ($F(2,34) = 1.25$, $p > .05$) (Fig. 2C).

fMRI results

The effect of Outcome (Optimum, Miss and Devil). The Optimum–Miss contrast activated left pallidum (MNI −12 10 −2), left ventromedial prefrontal cortex and adjacent parts of the medial orbitofrontal cortex (vmPFC/mOFC, MNI −6 56 8), bilateral putamen (left putamen, MNI −30 −4 8; right putamen, MNI 18 14 2), right caudate (MNI 10 16 2), and ventral anterior cingulate cortex (vACC, MNI −4 34 −4). The reverse contrast did not show suprathreshold activation. Moreover, right caudate (MNI 16 18 0) and bilateral putamen (left putamen, MNI −18 16 2; right putamen, MNI 30 16 −2) were significant in the Miss–Devil contrast. The reverse contrast did not show suprathreshold activation (Table 2).

Table 2. The effect of Outcome (Optimum, Miss, and Devil)

	Region	Peak activation				
		X	*Y*	*Z*	*t* value	Voxels
Optimum–Miss						
L	Cerebellum	−12	−80	−16	8.52	31,334
L	*Pallidum*	−12	10	−2	7.66	
R	*MCC*	6	−16	44	7.36	
L	*vmPFC*	−6	56	8	6.86	
L	*PCC*	0	−42	32	6.76	
R	*dACC*	4	18	26	5.98	
R	*Putamen*	18	14	2	5.84	
R	*Caudate*	10	16	2	5.71	
L	*Putamen*	−30	−4	8	5.56	
R	*vACC*	−4	34	−4	5.42	
R	Inferior frontal gyrus	38	34	10	5.35	614
L	Paracentral lobule	−8	−18	78	4.45	193
Miss–Optimum						
	No regions					
Miss–Devil						
R	Superior parietal lobule	14	−70	56	8.00	6129
R	Cerebellum	12	−60	−16	6.31	1821
R	Inferior frontal gyrus	48	36	26	5.54	1270
R	Caudate	16	18	0	6.66	739
R	*Putamen*	30	16	−2	4.54	
R	MCC	4	28	32	5.29	520
L	Putamen	−18	16	2	6.63	387
R	Inferior frontal gyrus	52	12	20	4.91	256
Devil–Miss						
	No regions					

Note. Coordinates (mm) are in MNI space. L = left hemisphere; R = right hemisphere. All the clusters survived FWE correction ($p < .05$) for multiple comparisons at the cluster level, with a voxel-level threshold corresponding to $p < .001$, uncorrected.

*Mood (regret vs. relief) * Mood Level (high vs. low) interaction effects in Miss trials.* Data analyses showed significant bilateral caudate activation (left caudate, MNI −8 22 −2; right caudate, MNI 14 24 4) in the (High Relief–Low Relief) − (High Regret–Low Regret) contrast (Fig. 3A). Left superior temporal gyrus (Left STG, MNI −60 −50 20) showed significant activation in the (High Regret–Low Regret) − (High Relief–Low Relief) contrast (Fig. 3B, Table 3).

Then, we extracted beta values of bilateral caudate (left caudate, MNI −8 22 −2; right caudate, MNI 14 24 4) and left STG (MNI −60 −50 20) identified in the above-mentioned contrasts. A post hoc paired-sample *t*-test revealed greater reward-related striatum (right caudate) activation in the High Relief condition than the Low Relief condition ($t(17) = 3.59$, $p < .01$). The right caudate showed no significant difference in activity between the High Regret condition and the Low Regret condition ($t(17) = 1.75$, $p > .05$) (Fig. 3A). The left caudate showed a similar activation pattern as the right caudate. Moreover, a paired-sample *t*-test revealed that activity in the left STG was greater for the High Regret than the Low Regret condition ($t(17) = 6.08$, $p < .01$) and no significant difference was found between the High Relief and Low Relief conditions ($t(17) = 1.06$, $p > .05$) (Fig. 3B).

Brain regions increasingly activated with changing relief or regret levels. In Gain trials, emotional ratings from −1 to −4 were used to signal the status of regret (extreme regret defined as −4) and emotional ratings from 1 to 4 were used to signal the status of relief (extreme relief defined as 4). Two sets of emotional ratings were used as the parametric regressors to identify brain regions responding to the increasing levels of regret or relief in gain (i.e., $\text{Regret}_{\text{Gain}}$ and $\text{Relief}_{\text{Gain}}$) trials. It was revealed that right caudate (MNI 22 24 12), left vmPFC/mOFC (MNI −12 −78 −8), and vACC (MNI −4 44 4) showed increased activations with increasing relief levels (Fig. 4A, Table 4). Moreover, left STG (MNI −60 −46 22) and left dorsomedial prefrontal cortex (dmPFC, MNI −4 50 36) showed increased activations with increasing regret levels (Fig. 4B, Table 4). In addition, no regions showed significant activations with decreasing levels of regret or relief in Gain trials.

The influence of Context (Follow advice vs. Not-Follow advice). Data analyses revealed significant dorsal anterior cingulate cortex (dACC, MNI 4 36 26, −4 38 26) in the Not-Follow–Follow contrast. The reverse contrast did not show suprathreshold activation (Fig. 5, Table 5). Moreover, the interaction between Context (Follow advice vs. Not-Follow advice) and Outcome (Optimum, Miss, and Devil) did not show suprathreshold activation.

DISCUSSION

The current study employed a modified sequential risk-taking task (Büchel et al., 2011; Brassen et al., 2012) to investigate the neural basis of regret and relief defined by subjective emotional ratings rather than win or loss outcomes *a priori*. Consistent with our prediction, the results showed the emotional ratings were modulated by both the obtained gain and the missed chance. Specifically, in Gain trials, participants felt relief if the RGP was more than 3/5 and felt regret if the RGP was less than 3/5. Along with prior studies (Büchel et al., 2011; Brassen

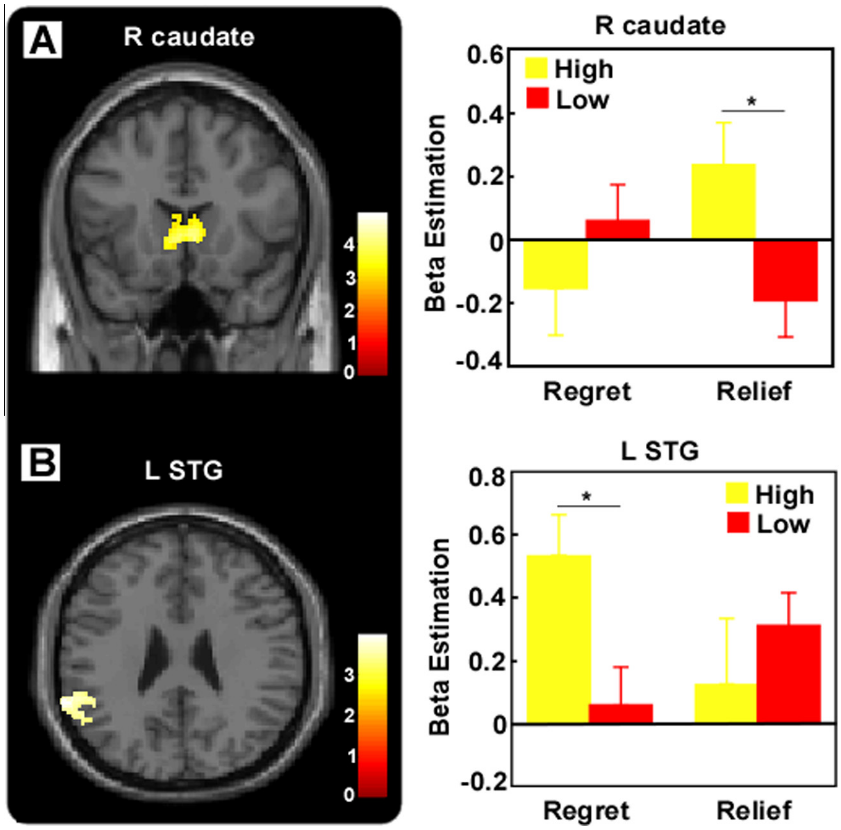

Fig. 3. Mood (regret vs. relief) * Mood Level (high vs. low) interaction effects in Miss trials. (A) Right caudate was significantly activated in the (High Relief–Low Relief) – (High Regret–Low Regret) contrast. A paired-sample t-test showed greater right caudate activation for the High Relief condition than the Low Relief condition ($t(17) = 3.59$, $p < .01$) and no significant difference between the High Regret condition and the Low Regret condition ($t(17) = 1.75$, $p > .05$). (B) Left superior temporal gyrus was significantly activated in the (High Regret–Low Regret) – (High Relief–Low Relief) contrast. A paired-sample t-test revealed that left superior temporal gyrus activation was greater for the High Regret than the Low Regret condition ($t(17) = 6.08$, $p < .01$) and no significant difference between High Relief and Low relief condition ($t(17) = 1.06$, $p > .05$).

Tale 3. The influence of advice-following

	Region	Peak activation				
		X	*Y*	*Z*	*t* value	Voxels
(High Relief–Low Relief) – (High Regret–Low Regret)						
L	Caudate	−8	22	−2	5.30	485
R	*Caudate*	14	24	4	4.62	
(High Regret–Low Regret) – (High Relief–Low Relief)						
L	SupraMarginal	−64	−46	26	3.96	272
L	*Superior temporal*	−60	−50	20	3.44	
L	*Middle temporal*	−58	−54	16	3.29	

Note. Coordinates (mm) are in MNI space. L = left hemisphere; R = right hemisphere. All the clusters survived FWE correction ($p < .05$) for multiple comparisons at the cluster level, with a voxel-level threshold corresponding to $p < .001$, uncorrected.

et al., 2012), the results revealed that the number of missed chances greatly influenced emotional ratings in the $\text{Regret}_{\text{Gain}}$ condition, suggesting that when feeling regret, participants tended to pay more attention to missed chances than to their obtained gain. On the other hand, in the $\text{Relief}_{\text{Gain}}$ condition, emotional ratings depended largely on the RGPs, which might reveal that participants focused on the trade-off between obtained gain and missed chance when they felt relief.

Moreover, the present results revealed that participants' emotional ratings in a given trial predicted their following behavioral changes in the next trial in the Gain_Gain condition. Specifically, the lower the emotional rating (i.e., more regret) on the current trial, the greater the difference ($\text{Opened Boxes}_{\text{Next}} - \text{Opened Boxes}_{\text{Current}}$) between the number of boxes opened in the current and successive trial. The results indicate that the more regret participants experienced in the current trial, the more risks they would take in the next trial, which is consistent with previous work showing that regret can exert a considerable impact on future behavior (Loomes and Sugden, 1982; Zeelenberg et al., 1998; Brassen et al., 2012). Notably, when conducting two simple regression analyses in the relief condition and regret condition separately, we found a significant regression coefficient in the relief condition, but not the regret condition. These results further suggest that regret and relief are separate emotional states.

In the current study, significant striatal activation was found in both the Optimum–Miss and Miss–Devil contrasts, consistent with a reward-related role of the striatum. Specifically, previous studies that have employed similar sequential risk-taking tasks have also identified striatal activity in the same two contrasts as

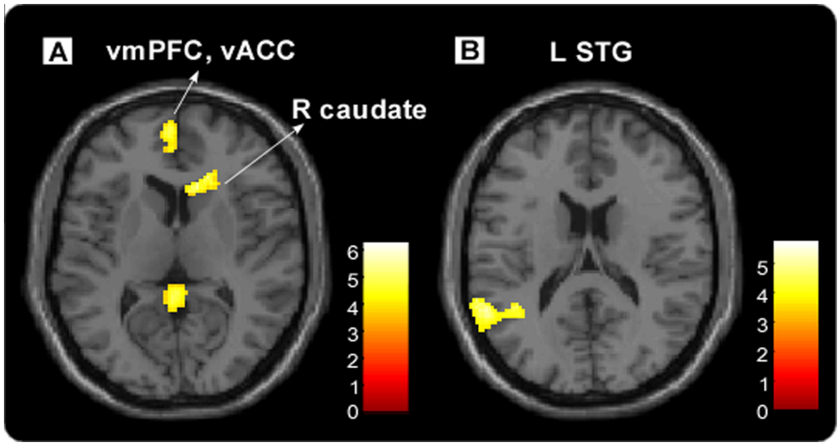

Fig. 4. (A) Right caudate, left vmPFC, and vACC showed increased activations with increasing levels of relief. (B) Left superior temporal gyrus showed increased activations with increasing levels of regret.

Table 4. Regions showing increased activations with the change of regret or relief level in Miss outcome

	Region	Peak activation			*t* value	Voxels
		X	*Y*	*Z*		
Increased with increasing relief level in Miss outcome						
L	PCC	−4	−36	32	6.30	1357
R	*MCC*	2	−42	42	6.76	
L	*MCC*	−2	−24	36	4.59	
R	Cerebellum	28	−84	−28	5.75	730
R	Caudate	22	24	12	4.99	281
L	vmPFC	−4	58	10	4.99	235
L	*vACC*	−4	44	4	4.47	
Increased with decreasing relief level in Miss outcome						
	No regions					
Increased with increasing regret level in Miss outcome						
L	SupraMarginal	−64	−46	24	5.75	582
L	*Superior temporal*	−60	−46	22	5.61	
L	dmPFC*	−4	50	36	4.91	123
Increased with decreasing regret level in Miss outcome						
	No regions					

Note. Coordinates (mm) are in MNI space. L = left hemisphere; R = right hemisphere. All the clusters survived FWE correction (p < .05) for multiple comparisons at the cluster level, with a voxel-level threshold corresponding to p < .001 ($^*p$ < 0.05), uncorrected.

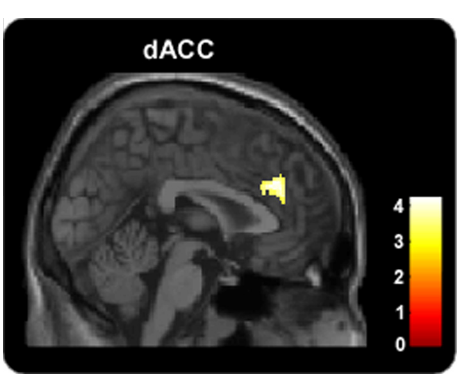

Fig. 5. Dorsal anterior cingulate cortex (dACC) was significantly activated in the Not-Follow–Follow contrast.

Table 5. The main effect of advice-following

	Region	Peak activation			*t* value	Voxels
		X	*Y*	*Z*		
Not-Follow–Follow						
R	dACC	4	36	26	4.26	346
R	*MCC*	2	34	30	4.22	
L	*dACC*	−4	38	26	3.94	
R	*dmPFC*	14	46	24	3.51	
Follow–Not-Follow						
	No regions					

Note. Coordinates (mm) are in MNI space. L = left hemisphere; R = right hemisphere. All Fthe clusters survived FWE correction (p < .05) for multiple comparisons at the cluster level, with a voxel-level threshold corresponding to p < .001, uncorrected.

mentioned above (Brassen et al., 2012). Furthermore, the current study found that the striatum, along with the vmPFC/mOFC and vACC, was positively related to relief level in general across different outcomes. A 'reward system' including the striatum and frontal gyrus, as well as vmPFC/mOFC and vACC, has been repeatedly found during decisions involving monetary rewards (Biele et al., 2011; Haber and Knutson, 2010; Izuma et al., 2008, 2010; John et al., 2003; Knutson et al., 2002; Schultz, 2002; Knutson et al., 2003; Koeneke et al., 2008). Rogers and colleagues (2004) revealed that positive outcomes for chosen gambles were associated with increased activity in vmPFC, vACC, and striatum. Xue et al. (2009) demonstrated the involvement of striatum and vmPFC/mOFC when participants received monetary rewards. It is worth noting that, in the current study, relief level was defined based on subjective emotional ratings instead of the amount of monetary gains. Thus, our work might help to further understand the role of the striatum in not only processing monetary reward, but also in relief-related processing.

Moreover, we observed increased dmPFC activation with increasing levels of regret in the current study (albeit at a more lenient threshold). This pattern has not been reported in previous research employing similar sequential risk-taking tasks (Brassen et al., 2012). We suggest our finding on dmPFC is achieved through sophisticated control over any confound by other emotions (e.g., relief), and it's in line with accumulating neuroanatomical evidence that reveal the correspondence between negative outcome feedback and activity in the dmPFC generally (Henderson et al., 2013). Especially, Chua et al. (2009) found dmPFC was involved in regret. In the current study, any trials subjectively rated as relief were excluded, making emotional rating for the remaining trials more 'purely' regret. Specifically, we also found increased superior temporal gyrus activation with increasing regret level. Previous research has shown activity in the superior temporal gyrus to be generally linked with the perception of negative emotions and negative outcomes (Bigler et al., 2007; Radua et al., 2010). For instance, Liu (2007) found that the superior temporal gyrus was significantly activated for negative reward (i.e., loss) processes during outcome evaluation. In the current study, participants might extract more negative emotion with increasing regret level. This could also be taken as proof of the validity of the subjective regret rating procedure in the current study.

In addition, we investigated the influence of advice-following on participants' responses to regretful and relieving outcomes. The behavioral results showed that participants tended to feel less regret when they did not follow advice than when they did. We propose that this behavioral result was in line with what a self-determination account (Deci and Ryan, 1985; Schwartz, 2000) would expect. According to the self-determination account, individuals are motivated to keep their autonomy. Following advice would actually violate one's independence, which results in greater regret. The account has been supported by several behavioral studies, revealing people experienced greater regret after following others' advice (Crawford et al., 2002), or showing voluntarily childless women were less likely to have child-related regret (Jeffries and Konnert, 2002). Besides, fMRI analyses in the current study found stronger dACC activation when participants did not follow advice than when they did. The dACC is known for its role in cognitive control and self-regulation (Brassen et al., 2012). For instance, Brassen et al. (2012) found that healthy elderly adults showed stronger ACC activation than depressed elderly adults when they were confronted with the negative experience of regret. Moreover, compared with depressed elderly adults, healthy elderly adults showed reduced regret responsiveness. We propose that participants use cognitive control strategies to successfully disengage from regretful experiences. This result most likely reflects the recruitment of cognitive control processes that support the regulation of regretful experiences.

CONCLUSION

Our results confirmed that participants may feel regret or relief in missed chance trials. Interestingly, participants felt relief if the RGP was more than 3/5 and felt regret if the RGP was less than 3/5. Moreover, relief was modulated by the trade-off between obtained gain and missed chance, while regret was mainly dependent on the number of missed chances. The results also showed participants tend to be risk-taking after they felt regret and risk-averse after they felt relief. Striatum, vmPFC/mOFC, and vACC showed increased activations with increasing levels of relief. Moreover, dmPFC and left STG activity was found at high levels of regret. In addition, the advice-taking context affected participants' reports of regret and relief. Less feelings of regret and stronger dACC activation were found after they did not follow the advice than when they did.

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