The Influence of Emotion Regulation on Decision-making under Risk

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Abstract

■ Cognitive strategies typically involved in regulating negative emotions have recently been shown to also be effective with positive emotions associated with monetary rewards. However, it is less clear how these strategies influence behavior, such as preferences expressed during decision-making under risk, and the underlying neural circuitry. That is, can the effective use of emotion regulation strategies during presentation of a reward–conditioned stimulus influence decision-making under risk and neural structures involved in reward processing such as the striatum? To investigate this question, we asked participants to engage in imagery-focused regulation strategies during the presentation of a cue that preceded a financial decision-making phase. During the decision phase, participants then made a choice between a risky and a safe monetary lottery. Participants who successfully used cognitive regulation, as assessed by subjective ratings about perceived success and facility in implementation of strategies, made fewer risky choices in comparison with trials where decisions were made in the absence of cognitive regulation. Additionally, BOLD responses in the striatum were attenuated during decision-making as a function of successful emotion regulation. These findings suggest that exerting cognitive control over emotional responses can modulate neural responses associated with reward processing (e.g., striatum) and promote more goal-directed decision-making (e.g., less risky choices), illustrating the potential importance of cognitive strategies in curbing risk-seeking behaviors before they become maladaptive (e.g., substance abuse). ■

INTRODUCTION

The ability to control emotional responses is essential for adaptive function. For instance, an individual unable to cope with sudden urges elicited by a conditioned stimulus (CS; e.g., casino environment) may engage in maladaptive risk-seeking behavior (e.g., gambling) that can potentially turn into a compulsive disorder (Kushner et al., 2007). One promising intervention is the application of cognitive strategies during the emotion generation process, a practice known as emotion regulation, which results in an alteration in the affective experience of emotional stimuli (Ochsner & Gross, 2005). The use of such cognitive strategies has been shown to decrease physiological and subjective responses associated with the expectation of prospective monetary rewards, which in turn modulate BOLD responses in the striatum (Staudinger, Erk, Abler, & Walter, 2009; Delgado, Gillis, & Phelps, 2008), a region previously associated with reward-related processing (Haber & Knutson, 2010; Rangel, Camerer, & Montague, 2008; Delgado, 2007; O'Doherty, 2004).

It is unclear, however, if the effects of emotion regulation can extend beyond changes in emotional experience to changes in goal-directed behavior. Affective responses elicited by salient cues are known to influence behavior, for instance, cue-induced drug craving is associated with increased drug seeking (Weiss, 2005). Recently, application of regulation strategies to drug cues has been found to reduce subjective feelings of craving in cigarette smokers (Kober, Kross, Mischel, Hart, & Ochsner, 2009) and in cocaine abusers (Volkow et al., 2010) and lead to decreased activation in regions such as the ventral striatum. Although these studies did not probe shifts in behavior associated with regulation of craving, it is possible that regulation of such conditioned cues can extend to risk-taking behaviors such as drug seeking. The goal of the current study was to examine the effect of cognitive regulation of a conditioned cue on subsequent behavior in the normative brain. Specifically, this study probed if the successful use of cognitive strategies during presentation of a CS (e.g., slot machine) would influence decision-making under risk (e.g., gambling) and associated neural circuits such as the striatum.

One hypothesis was that emotion regulation would lead to increased risk-seeking behavior, as individuals who successfully regulate tend to make choices that maximize performance (Seo & Barrett, 2007) and place less weight on the outcome of a single decision, in turn leading to a reduction in loss aversion (Sokol-Hessner et al., 2009). An alternative hypothesis, however, was that exerting cognitive control over emotional responses would promote more goal-directed decision-making, thus attenuating risky decisions and associated BOLD signals in the striatum. This hypothesis was motivated by previous observations that imagery-focused regulation modulated the expectation of reward and BOLD responses in reward-related areas

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(Delgado, Gillis, et al., 2008). The multifaceted human striatum is a region often identified during investigations of risky decision-making (Christopoulos, Tobler, Bossaerts, Dolan, & Schultz, 2009; Kuhnen & Knutson, 2005; Matthews, Simmons, Lane, & Paulus, 2004), whose signals correlate with drug-specific cravings (Sinha et al., 2005) and impulsive, risky decisions in substance users (Leland, Arce, Feinstein, & Paulus, 2006). As previously mentioned, neural signals in the striatum have also been reported to be modulated by emotion regulation strategies during expectation of monetary (Staudinger et al., 2009; Delgado, Gillis, et al., 2008) and drug (Volkow et al., 2010; Kober et al., 2009) rewards. Thus, the striatum provides an ideal target for potential regulatory influences that may occur during decision-making under risk.

We investigated the effect of cognitive regulation on risk-taking and its neural correlates using a fMRI experimental paradigm that included both a cue and a decision phase. The cue phase consisted of the presentation of a CS (CS+ or CS−) and a cognitive instruction ("Look," "Relax," or "Excite"). The decision phase followed the cue presentation and comprised either a selection between risky and safe monetary lotteries (CS+ trials) or a nonmonetary control decision between two different stamps (CS− trials; Figure 1). Decision-making under risk was quantified as the proportion of trials in which the risky option was chosen for each type of cognitive instruction. Finally, we acquired postexperimental self-assessment of participants' perceived success in using the cognitive strategies to probe how the successful application of emotion regulation modulates decision-making under risk and its associated neural correlates.

METHODS

Participants

Thirty-five right-handed volunteers participated in this study (17 women and 18 men). Three participants were excluded because of their failure to comply with task requirements (assessed by postexperimental questionnaires), which included not following instructions and using an incorrect strategy. One additional participant was excluded because of indifference during task performance as assessed by behavior (i.e., participant consistently chose one response) and self-report. Finally, data from one MRI session was excluded because of equipment malfunction. Thus, final analysis was conducted on 30 participants (15 women and 15 men; mean age = 20.87, *SD* = 2.99). Participants responded to posted advertisements and gave informed consent according to the Rutgers University Institutional Review Board for the Protection of Human Subjects in Research and the Newark Campus Institutional Review Board of the University of Medicine and Dentistry of New Jersey.

Procedure

The experimental task consisted of 90 trials, divided into six blocks of 15 trials. Each trial started with the cue phase, involving the presentation of a CS (a slot machine, CS+ or stamp machine, CS−) and a cognitive instruction (Look, Relax, or Excite) for a variable duration of 4, 6, or 8 sec (Figure 1). The CS indicated if the trial presented an opportunity to earn money (CS+) or not (CS−). The cognitive instruction was presented above the CS and directed

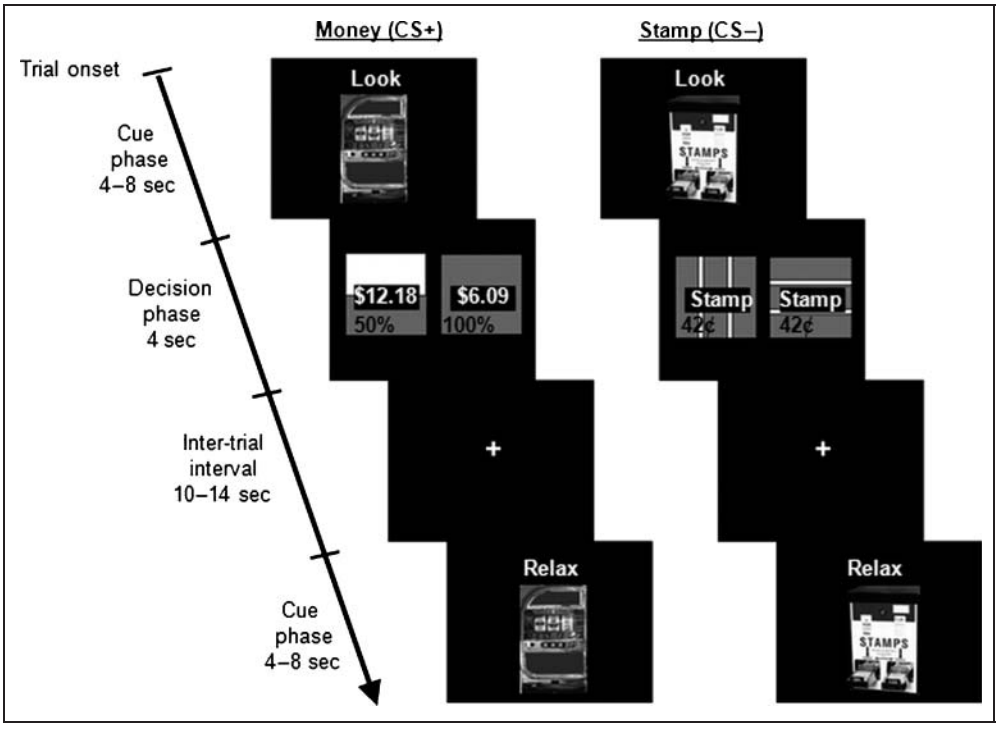

Figure 1. The paradigm consisted of the presentation of a picture of a CS and a cognitive instruction. The CS was either a slot machine (CS+), which predicted a monetary decision between a safe and a risky lottery, or a stamp machine (CS−), which predicted a nonmonetary choice between stamps. Participants applied emotion regulation strategies (Relax or Excite) or acted naturally (Look) during presentation of both CS trials, followed by a decision-making phase.

participants to either (a) respond naturally to the slot machine, that is, think about the decision coming up and the chance to win money ("Look"); (b) engage in imagery-focused regulation by imagining a calming scene ("Relax"), or (c) imagine an exciting scene ("Excite"). The instructions were adapted from previous experiments that used an imagery-focused regulation strategy (Delgado, Gillis, et al., 2008; Delgado, Nearing, LeDoux, & Phelps, 2008), initially on the basis of more traditional emotion regulation techniques (Ochsner et al., 2004; Ochsner, Bunge, Gross, & Gabrieli, 2002). The cue phase was followed by the decision phase, where participants were presented with two options for a fixed duration of 4 sec. For CS+ trials, participants chose between two monetary options: a gamble (risky option) and a guaranteed amount (safe option) that varied with respect to probability and amount. For CS− trials, the decision carried no affective significance, as participants chose between two different representations of postage stamps with no monetary value. A jittered 10- to 14-sec intertrial interval followed the decision phase.

Participants received no immediate feedback about the outcomes of their decisions. To ensure the perception that each decision was independent and significant, six decisions (lotteries) were realized during the experimental session. These outcome sessions occurred during three specific periods during the experiment. The first outcome session occurred after the initial two task blocks and, as a result, reflected the resolution of those two task blocks. That is, two decisions were resolved, with one decision being chosen from each of the two blocks just completed. The second outcome session occurred after task blocks 3 and 4, whereas the third and final outcome session occurred at the end of the experiment (after task blocks 5 and 6). During each of these three outcome sessions, participants first saw the computer select two decisions from the five possible decision types by spinning a wheel. Next, they watched the experimenter open their data file to identify their choices (risky or safe option) for those decisions. Finally, participants were informed by the experimenter over the intercom of the outcomes of the decisions and how much money they had won. Participants were compensated a base rate of $20 plus whatever money they earned from the six selected decisions. The decisions selected were the same for all participants leading to an average earning of $53.33 ($SD$ = $4.08).

Before scanning, participants were extensively trained on the task instructions, especially the application of the emotion regulation techniques. They were informed that pictures of a slot machine and a stamp machine would serve as cues to signal upcoming decisions involving either money or stamps, respectively. They were also informed that a word presented above the picture would serve as the instruction for that trial. There were three such instructions: "Look," "Relax," and "Excite." When instructed to "Look," participants were asked to look at the picture while it was presented on the screen and react naturally while contemplating its significance for them in this "game." More specifically, when the instruction Look was paired with the slot machine, they were asked to think that they would have to make a financial decision, and on the basis of their choice, they could potentially win money. In contrast, when the instruction Look was paired with the stamp machine, they would think about a potential decision between two stamps with no financial outcome. When instructed to "Relax," participants were prompted to imagine a calming scene, such as a sunny day in a park. During the training period, each participant generated his or her own image with guidance from the experimenter with the requirements that such imagery would be relaxing and easy to conjure up to facilitate regulation. Participants were instructed to think of the same image each time the word Relax was presented, irrespective of type of trial (CS+, CS−). Finally, participants were also presented with a third instructional cue named "Excite." For the excite emotion regulation instruction, participants were to imagine an exciting scene, such as a roller coaster ride, to increase their arousal.

There were five different financial decisions in the task (Table 1). Each lottery included a risky option with one of five different levels of probability (.20, .35, .50, .65, .80) and a safe option with an amount equivalent to the expected value of the gamble (e.g., risky: 20% chance of winning $10.35 or safe: 100% chance of winning $2.07). The location (right or left side of screen) of the risky and safe options was counterbalanced. For CS− trials, participants made decisions between two stamps with different patterns, with four types of stamps included overall and presentation location being counterbalanced. Participants used an MRI compatible response unit and used either the index or middle finger of the right hand to make a decision during both CS+ and CS− trials. Thus, the experiment included six different types of trials that varied in respect to cognitive strategy (Look, Relax, and Excite) and affective significance of decision (CS+ and CS−). There were 60 CS+ trials with 20 of each instruction and 30 CS− trials with 15 of each instruction. The five different financial decisions were repeated 12 times (four times with each instruction).

Table 1. Financial Decisions Included in Experimental Paradigm

	Risky Option		*Safe Option*	
Lottery	*Probability*	*Value*	*Probability*	*Value*
1	.20	$10.35	1	$2.07
2	.35	$11.66	1	$4.08
3	.50	$12.18	1	$6.09
4	.65	$6.28	1	$4.08
5	.80	$2.59	1	$2.07

At the conclusion of the scanning session, participants completed several questionnaires, including a postexperimental questionnaire that assessed compliance with the emotion regulation demands and measured perceived successful use of cognitive strategies. Additional questionnaires that considered potential individual differences included a measure of risk preferences (Holt & Laury, 2002), use of emotion regulation strategies (Emotion Regulation Questionnaire; Gross & John, 2003), and behavioral inhibition and activation (Carver & White, 1994). Finally, at least a day after the scanning session, participants were asked to complete a paper questionnaire with the five financial decisions from the scanner task along with two variations, where the amounts were either increased or decreased by $0.50. This additional questionnaire allowed for the evaluation of individual's choice preferences in the absence of any regulation instruction.

fMRI Acquisition and Analysis

Imaging data were acquired using a 3T Siemens Allegra head-only scanner with a standard head coil at Rutgers University Heights Center for Advanced Imaging. Structural images were acquired using a T1-weighted sequence (256 × 256 matrix, 176 1-mm sagittal slice). Functional images were acquired using a single-shot gradient-echo EPI sequence (TR =2000 msec, TE = 25 msec, field of vision = 192 cm, flip angle = 80°, bandwidth = 2604 Hz/px, echo spacing = 0.29 msec). Thirty-five contiguous (3 × 3 × 3 mm voxels) oblique-axial images were acquired parallel to the AC–PC line. Imaging data analysis was performed with Brain Voyager software (version 1.9; Brain Innovation, Maastricht, the Netherlands). Data were corrected for excessive motion (using a cutoff of 2 mm within a run), and slice scan time adjustments were made using sinc interpolation. Spatial filtering was performed using a three-dimensional Gaussian filter (4 mm FWHM), whereas temporal filtering was used with voxel-wise linear detrending and high-pass filtering of frequencies (three cycles per time course). Finally, structural and functional data for each participant were transformed into standard Talairach stereotaxic space (Talairach & Tournoux, 1988).

A random effects analysis was performed on the functional data using a general linear model (GLM) that estimated beta weights for two boxcar predictors (cue phase and decision phase) and one parametric predictor time-locked to the onset of the decision phase that varied in accordance to the five levels of probability (.20, .35, .50, .65, .80). This analysis allowed for the nonbiased identification of functionally defined ROIs involved in decision-making under risk. Previous studies have examined neural coding of expected value of rewards (e.g., Knutson & Cooper, 2005) and how this process is modulated by emotion regulation (Staudinger et al., 2009; Delgado, Gillis, et al., 2008); thus, a goal of the current study was to extend that research by probing neural coding of risk (i.e., probability) information during decision-making and examining modulation by emotion regulation. Statistical maps were created using the false discovery rate method with a threshold of $q < 0.01$ (Genovese, Lazar, & Nichols, 2002), and functional ROIs were extracted on the basis of a peak voxel center and a cluster extent of 10 voxels in all directions. To test for modulation by emotion regulation, mean parameter estimates (i.e., beta weights) were extracted from the functional ROIs defined by the parametric probability predictor using a second GLM that included 18 different predictors that indicated the instruction (Look, Relax, and Excite) and subsequent choice (risky, safe, and stamp) at the time of the cue phase and the instruction (Look, Relax, and Excite) and choice (risky, safe, and stamp) at the time of the decision phase. Additionally, missed trials and six motion parameters were included as predictors of no interest. ANOVA tests were then performed on the extracted beta weights to probe the effects of emotion regulation on decision-making under risk during the decision phase (Table 2).

RESULTS

Behavioral Results

Subjective Ratings

Subjective ratings of excitement experienced during presentation of the CS+ (the slot machine) and the CS− (the stamp machine) cues were acquired throughout the experiment to verify the affective value attributed to CS+ trials. Specifically, these ratings were collected six times during the experimental task, once after each of the six experimental blocks of trials, and were independent of the emotion regulation manipulation (i.e., did not include the instruction words Look, Relax, and Excite). Participants rated how excited they felt when they saw the slot machine and the stamp machine using a Likert scale (1 = not at all excited; 7 = extremely excited). Using ratings from all participants, a comparison of the averaged ratings was made with a repeated measures ANOVA with CS type (slot machine, stamp machine) as a within-subjects factor. Participants felt significantly more excited about the slot machine ($M = 5.32$, $SD = 0.83$) than the stamp machine ($M = 2.97$, $SD = 1.19$) during the task [$F(1, 29) = 107.07$, $p < .001$], suggesting that participants associated the slot machine cue with an opportunity for reward.

After the scanning session, all participants completed a postexperiment questionnaire, which addressed whether they had effectively used the two imagery-focused regulation strategies. Specifically, participants rated how successful they were at visualizing relaxing imagery using a Likert scale in which 1 = not at all successful and 7 = very successful. Participants also completed this rating for the excite visualization. These subjective ratings provide an index of regulation success, and they suggest that participants felt fairly successful at the Relax ($M = 5.07$, $SD = 1.76$) and Excite ($M = 5.43$, $SD = 1.48$) techniques.

Table 2. Regions that Correlated with Increasing Probability of Reward in the Regulator Group, q(FDR) < 0.01

		Talairach Coordinates				
Region of Activation	*Laterality*	*x*	*y*	*z*	*Voxels*	*t Stat*
Superior frontal gyrus (BA 6)	L	−3	−16	55	161	6.39
Medial frontal gyrus (BA 32/6)	R	6	2	49	347	6.00
Medial frontal gyrus (BA 32/6)	L	−3	0	49	365	5.35
Inferior frontal gyrus (BA 44)	L	−39	8	31	119	6.69
Insula	L	−36	5	13	132	5.73
Ventral striatum	L	−15	5	4	340	7.38
Thalamus	L	−6	−10	4	342	6.86
Ventral striatum	R	12	2	1	284	6.61
Thalamus	R	6	−16	1	283	7.12
Insula	L	−36	11	−2	300	8.79
Hippocampus	R	21	−28	−2	194	7.48
Midbrain	R	6	−22	−8	889	11.40
Midbrain	L	−6	−16	−8	747	9.54
Midbrain	L	−6	−25	−8	850	8.72
Lingual gyrus (BA 17)	R	18	−91	−8	804	8.81
Lingual gyrus (BA 17)	L	−18	−94	−8	344	7.46
Occipital Lobe (BA 18)	R	24	−85	−14	544	8.08
Cerebellum	L	−1	−49	−28	200	5.76

BA = Brodmann's area; L = left; R = right; FDR = false discovery rate.

Decision-making

Decision-making under risk was quantified as the proportion of trials in which the risky option was chosen for each instruction type (Look, Relax, and Excite). To examine the effect of regulation (Relax and Excite) on risk taking, a repeated measures ANOVA with type of instruction as a within-subjects factor and success ratings for relax and excite regulation as between-subjects factors was estimated. Success ratings were included to account for the observed individual differences in application of the emotion regulation strategies. The ANOVA revealed a significant main effect of instruction [$F(2, 32) = 5.47$, $p < .01$], suggesting that cognitive strategies can influence decision-making under risk. Moreover, a trend that approached significance for an interaction of instruction and relax success ratings was observed [$F(8, 32) = 2.03$, $p = .07$]. Specifically, participants who experienced perceived success in applying the relax strategy chose the risky option less often during Relax compared with Look trials. A similar analysis investigating the interaction of instruction and excite success ratings was not significant, however [$F(8, 32) = 1.08, p = .40$]. These results suggest that when presented with a conditioned cue that represents reward, engaging in relax-focused emotion regulation, but not excite-focused emotion regulation, alters subsequent decision-making.

Given the effectiveness of the relax-focused regulation and the lack of excite-focused regulation effects, all subsequent analyses excluded the excite condition. To further probe the observed effect of the relax emotion regulation strategy on risk-taking, we divided participants into two groups on the basis of their relax visualization success rating. Participants who rated themselves as successful (ratings of 5–7) were considered to be effective regulators ($n = 20$), whereas those that rated their performance as neutral or unsuccessful (ratings of 1–4) were considered to be nonregulators ($n = 10$). Notably, participants in the regulators group rated the relax strategy as significantly easier to implement than participants in the nonregulators group [regulators: $M = 6.3$, $SD = 0.73$; nonregulators: $M = 4.5$, $SD = 1.84$; $t(28) = 3.85$, $p < .001$].

Using these two groups, the effect of emotion regulation on decision-making was probed with a repeated measures ANOVA using type of instruction (Look, Relax) as a within-subjects factor and group (regulator, nonregulator) as a between-subjects factor. A significant interaction of type of instruction and group was found [$F(1, 28) = 4.20$, $p < .05$], suggesting that regulator status influenced the effect of the relax emotion regulation strategy on decision-making.

We then compared the proportion the risky option was chosen across each instruction type (Look, Relax) for both the regulator and nonregulator groups separately (Figure 2). In the regulators, the proportion that the risky option was chosen was lower during Relax compared with Look trials [$t(19) = 2.19, p < .05$], suggesting that the successful use of emotion regulation strategies can modulate decision-making under risk. This difference in decision-making across instruction was not observed in the nonregulators [$t(9) = 1.11, p = .30$].

To ensure the observed change in risk-taking in the regulator group was because of decreases in risk-taking associated with successful use of the relax emotion regulation strategy and not increases in risk-taking associated with the Look condition, we assessed decision-making in the absence of any instruction cues. Specifically, participants were asked to complete a questionnaire with 15 financial decisions, which consisted of the five financial decisions from the scanner task and two variations (the amounts ± $0.50). This questionnaire was completed at least 1 day after the scanning session and was administered without the use of any explicit cognitive strategy. Participants' choices in this follow-up decision-making questionnaire did not differ from those observed in the Look condition for either group of participants, supporting the main result of decreases in risky behavior after successful use of the relax emotion regulation strategy.

Decision-making: Reaction Time

An ANOVA was performed to probe differences in RT using instruction (Look and Relax) and choice (risky and safe) as within-subjects variables and group (regulator, nonregulator) as a between-subjects variable. No significant effects were observed for any of the contrasts, suggesting that RT did not differ as a function of instruction or choice, or across regulators and nonregulators.

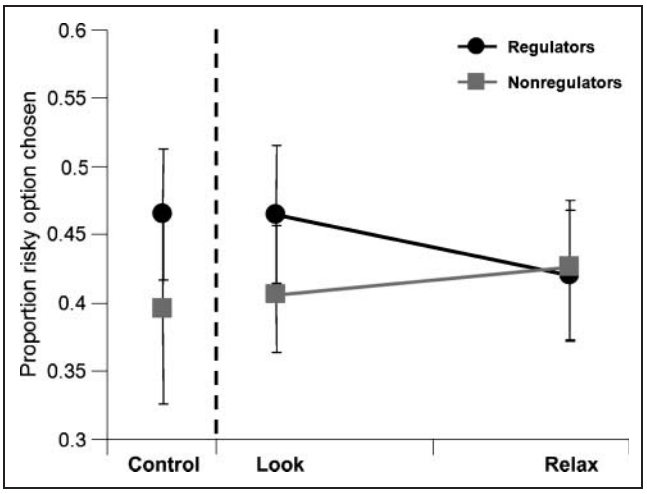

Figure 2. Decrease in risky behavior as a function of successful regulation is displayed for the regulator group (± *SEM*).

Comparison of Regulators and Nonregulators on Individual Differences Measures

All participants completed a series of questionnaires to probe potential individual differences. As previously described, the postexperimental questionnaire divided participants into regulators and nonregulators on the basis of their perceived success in using the imagery-focused regulation strategy. Although these groups differed with respect to how emotion regulation influenced their decision-making, we did not find differences between the groups on any of the individual difference measures we obtained. Regulators and nonregulators did not show different levels of risk aversion as assessed by the Holt and Laury (2002) questionnaire, suggesting that the different patterns of decision-making observed in these groups were not because of different risk preferences. These groups also did not differ on the subscale scores of the Emotion Regulation Questionnaire, which assesses use of emotion regulation in daily life (Gross & John, 2003). Finally, the groups showed no differences in approach- and avoidance-focused motivation as measured by the Behavioral Inhibition and Activation Scales (Carver & White, 1994). Although it is possible that these groups may differ in ways not probed by these selected questionnaires, the results highlight the major difference between the two groups as their success at visualizing the relaxing imagery.

Neuroimaging Results

Neuroimaging analysis focused on the decision phase and sought to indentify brain regions recruited during decision-making that were modulated by emotion regulation. Regions of the brain involved in processing risk and reward were identified using a GLM in which the probability of winning each risky lottery (.20, .35, .50, .65, .80) was included as a parametric regressor time-locked to the onset of the decision phase. This GLM revealed brain regions whose BOLD signals correlated with increasing probability of reward, including various structures that have been previously associated with risky decision-making in humans: the striatum with a loci of activation that extended ventrally (Christopoulos et al., 2009; Hsu, Krajbich, Zhao, & Camerer, 2009; Tom, Fox, Trepel, & Poldrack, 2007; Kuhnen & Knutson, 2005; Matthews et al., 2004), the midbrain (Tom et al., 2007), the insula (Kuhnen & Knutson, 2005), and the medial frontal cortex (Christopoulos et al., 2009; Engelmann & Tamir, 2009).

Modulation of ventral striatum activity by emotion regulation was an a priori prediction. To test for effects of emotion regulation, a second GLM was applied to the left ventral striatum ROI to extract mean beta weights. This GLM included cue phase and decision phase predictors that each specified the type of instruction (Look, Relax, and Excite) and option chosen (risky and safe). The cue and decision phase predictors were matched in starting time and duration to their task events. The decision phase

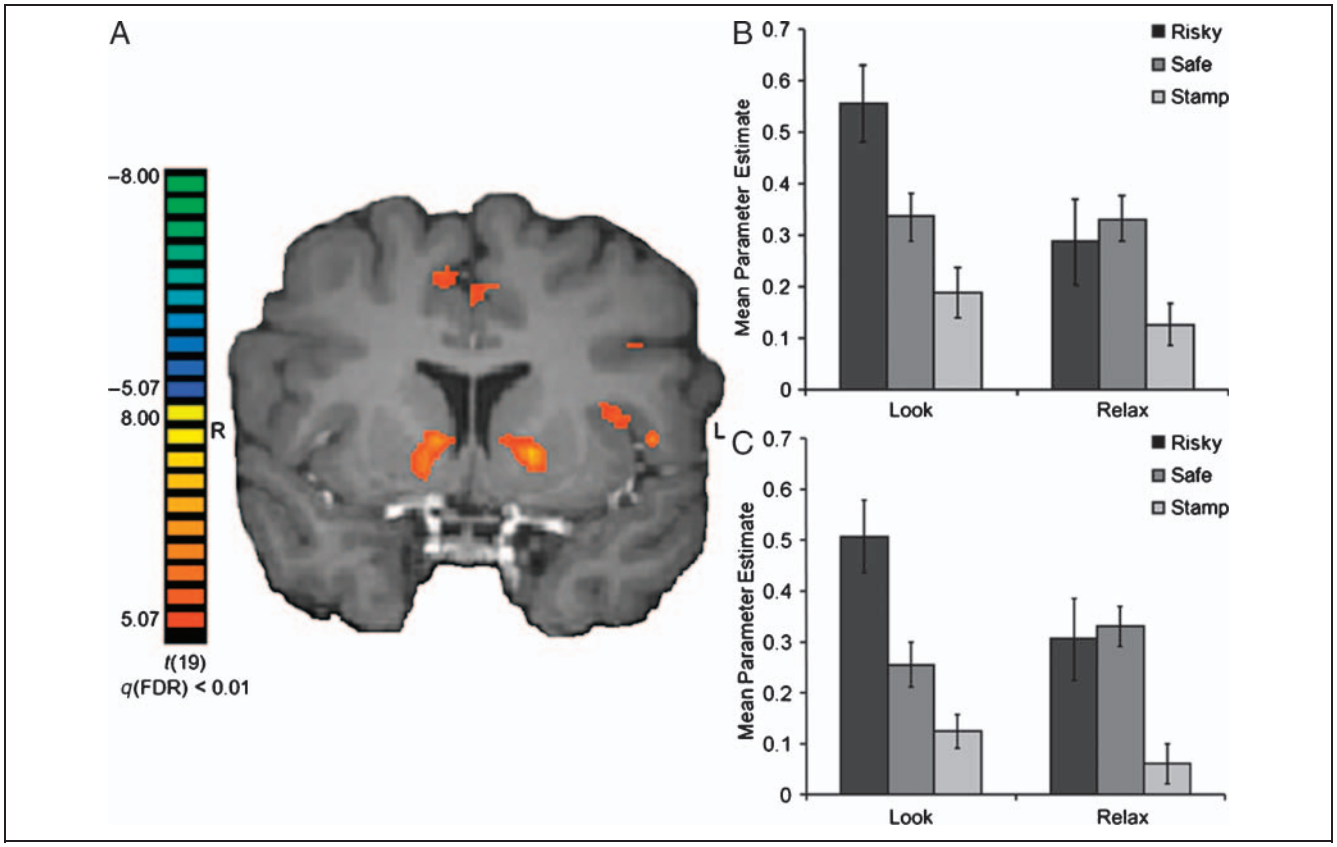

Figure 3. (A) Bilateral striatum correlated with increasing probability of reward during decision-making under risk. (B) Mean parameter estimates for left ventral striatum reveal an interaction between instruction (Look, Relax) and choice (risky and safe). (C) A similar result is observed in the right ventral striatum (± *SEM*).

beta weights were input into a repeated measures ANOVA with instruction and choice as within-subjects factors and success ratings for relax and excite regulation as between-subjects factors. The ANOVA demonstrated a significant interaction of instruction and choice [$F(2, 30) = 4.70$, $p < .05$] and a trend for an interaction of instruction, choice, and relax success rating [$F(8, 30) = 1.94$, $p = .09$] in the left ventral striatum. Echoing the behavioral analysis, there were no interactions involving excite success ratings [$F(8, 30) = 1.25$, $p = .30$]. Post hoc paired t tests showed that, in trials without emotion regulation (Look), the BOLD response was significantly greater when participants made risky choices compared with safe ones [$t(29) = 2.49$, $p < .05$]. This heightened natural response to risky choices was diminished in the relax regulation trials [$t(29) = 0.81$, $p = .42$], suggesting that regulation modulated activity associated with risky choices.

Regulators: Emotion Regulation of Decision-making under Risk

Given the influence of the relax emotion regulation strategy on risk taking observed in the behavioral results, along with the lack of behavioral or neural effects with the excite regulation strategy, additional neuroimaging analyses were conducted focusing specifically on the regulators group defined by relax success ratings. Using the 20 regulator participants, regions whose BOLD signals correlated with increasing probability of reward were identified with the parametric GLM described above. Of particular interest are results highlighting the modulation of both left and right ventral striatum BOLD signals during risky decision-making by the relax emotion regulation strategy (Figure 3A). In the left ventral striatum (Figure 3B), a main effect of instruction [$F(1, 19) = 6.85$, $p < .05$], a trend for a main effect of choice approaching significance [$F(1, 19) = 4.25$, $p = .05$], and an interaction of instruction and choice [$F(1, 19) = 6.76$, $p < .05$] were observed. Specifically, greater BOLD signals in the left ventral striatum were observed when participants chose the risky option compared with when they chose the safe option during trials where they were acting naturally [Look condition: $t(19) = 3.51$, $p < .005$], but not after they used emotion regulation strategies [Relax condition: $t(19) = 0.63$, $p = .54$] as assessed by post hoc paired t tests. Across types of instruction, BOLD signals were lower during Relax than Look when the choice was the risky option [$t(19) = 2.90$, $p < .01$], whereas no significant effects of instruction were found when the decision was to take the safe option [$t(19) = 0.08$, $p = .94$]. Finally,

beta weights associated with control decisions (CS−), a choice between two postage stamps, were also obtained. Although both Look and Relax instructions were used in the control trials, no modulation was expected in the ventral striatum as the control decisions did not involve risky propositions or rewards. As expected, no significant differences between Look and Relax beta weights for the control condition were seen, suggesting that emotion regulation effects were particular to trials where a risky decision was presented.

Similar patterns emerged in the right ventral striatum (Figure 3C), depicted by a trend approaching significance for a main effect of instruction [$F(1, 19) = 3.70, p = .07$], a significant main effect of choice [$F(1, 19) = 4.88, p < .05$], and an interaction of instruction and choice [$F(1, 19) = 7.06, p < .05$]. Greater activity in the right ventral striatum was observed when participants chose the risky option compared with when they chose the safe option during trials in which they acted naturally [Look condition: $t(19) = 4.00, p < .001$], but not after using emotion regulation [Relax condition: $t(19) = 0.31, p = .76$]. Additionally, BOLD signals were influenced by instruction; specifically, activity was lower during Relax than Look when the choice was risky [$t(19) = 2.53, p < .05$], as observed on the left striatum ROI. Interestingly, when the choice was the safe option, in this ROI only, BOLD signals were greater during Relax than Look [$t(19) = 2.18, p < .05$]. There were no emotion regulation effects on the BOLD response for control decisions (CS− trials). Taken together, these results suggest that the relax emotion regulation strategy modulated brain activity in the striatum associated with decision-making under risk, particularly decreasing BOLD responses when choosing a risky option.

An additional analysis was performed to test if a specific level of probability (e.g., .50) was driving the observed pattern of BOLD signals in the striatum. Mean beta weights were extracted from the left ventral striatum region previously defined by the parametric analysis of probability of reward using a model that included predictors for instruction (Look, Relax) and level of probability (.20, .35, .50, .65, .80). These beta weights were entered into a repeated measures ANOVA, which revealed a main effect of instruction [$F(1, 19) = 5.46, p < .05$] and a trend for a main effect of probability [$F(4, 76) = 2.07, p = .09$]. Importantly, this region did not show a significant interaction of instruction and probability [$F(4, 76) = 0.27, p = .89$]. The lack of interaction between instruction and level of probability coupled with the significant main effect of instruction suggests that the decreased activity associated with risky choices observed in the Relax condition is not primarily driven by one particular level of probability in this paradigm.

To probe potential interactions between the ventral striatum and other regions, an exploratory correlation analysis was performed using the left ventral striatum. Specifically, a whole brain correlation was conducted using the left ventral striatum ROI as the seed region, which served to identify regions that may be functionally connected with the striatum. The resulting statistical parametric map was thresholded at $p < .01$ using conservative Bonferroni corrections for multiple comparisons. A cluster in the dorsal medial pFC, located in the dorsal cingulate cortex ($x, y, z, = 2, 7, 42$), was observed to correlate with BOLD signals in the left ventral striatum. A post hoc test of this region during the use of emotion regulation strategies was further conducted by extracting beta weights using a simplified GLM with instruction predictors (e.g., Look and Relax) during the cue phase. This post hoc paired t test revealed that beta weights for Relax (regulation condition) trials tended to be greater than those for Look (no regulation condition [$t(19) = 1.81, p = .09$]). Although these results are deemed exploratory, they suggest that one potential region engaged in emotion regulation that is mediating control over the striatum during decision-making is the dorsal medial pFC, particularly the dorsal cingulate cortex—a topic for future research.

Additional Regions Showing Modulation by Emotion Regulation in the Regulators Group

Within other regions that correlated with increasing probability of reward during decision-making, only regions in the midbrain, insula, and superior frontal gyrus (BA 6; encompassing premotor cortex and SMA) were found to be modulated by instruction and/or choice in the regulators group. An ANOVA performed with beta weights extracted from the left midbrain, for instance, showed a significant interaction of instruction and choice [$F(1, 19) = 4.60, p < .05$], with a pattern of results resembling the striatum (Figure 4A). Specifically, when participants chose the risky option, a paired t test revealed that activity in the regulation condition was significantly lower than that in the Look condition [$t(19) = 2.32, p < .05$], although no differences for safe choices were seen [$t(19) = 0.38, p = .71$]. In the right midbrain region, a main effect of instruction was observed [$F(1, 19) = 5.16, p < .05$]. During the CS− decisions, BOLD signals in the left and right midbrain region did not vary as a function of instruction.

A trend for an interaction of instruction and choice was also observed in the left anterior insula [$F(1, 19) = 3.92, p = .06$], although a main effect of choice was the primary effect in this ROI [$F(1, 19) = 5.01, p < .05$; Figure 4B]. Interestingly, a different pattern was apparent in a smaller, more dorsal anterior insula ROI in the left hemisphere, where a main effect of instruction was observed [$F(1, 19) = 5.76, p < .05$], characterized by decreased activation during regulation. In both insula ROIs, activity during CS− decisions was not affected by instruction. Finally, activity in the left superior frontal gyrus (BA 6) during financial (CS+), but not control (CS−), decisions demonstrated a main effect of instruction [$F(1, 19) = 12.23, p < .01$], such that activity was decreased after regulation compared with after natural responding.

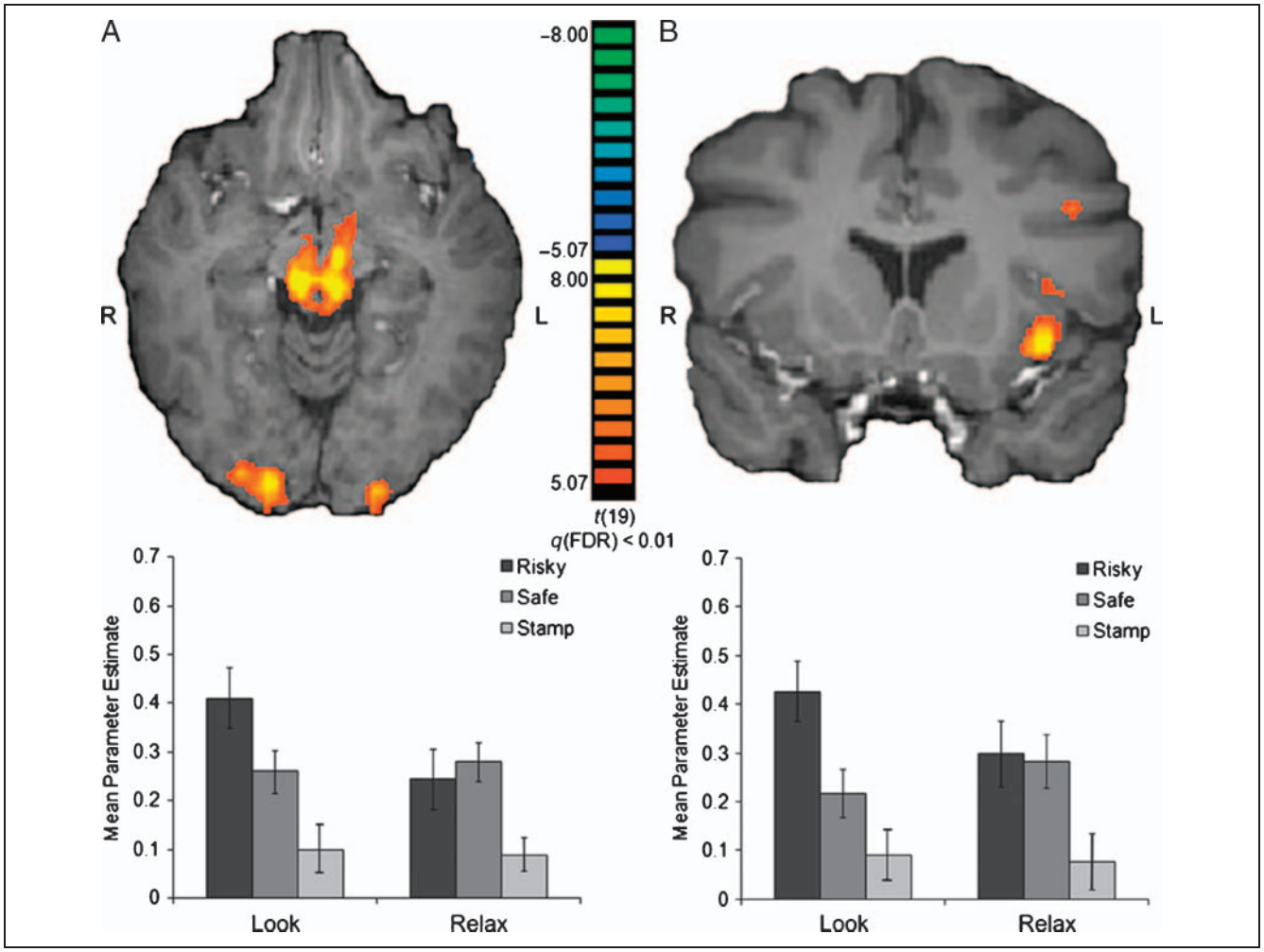

Figure 4. The effect of instruction and choice in (A) the midbrain and (B) the insula. The left midbrain BOLD responses demonstrated an interaction of instruction and choice, such that activity to risky choices was significantly reduced after regulation (Relax) compared with after responding naturally (Look). A main effect of choice was observed in the left anterior insula, with greater responses to risky compared with safe choices (± *SEM*).

Nonregulators: Emotion Regulation of Decision-making under Risk

Two exploratory analyses were conducted to test for effects of instruction and choice in the nonregulator sample (n = 10). First, using the left ventral striatum ROI defined by the regulator group parametric risk analysis, we extracted mean beta weights for the nonregulators with the model that included instruction and choice predictors. An ANOVA found no significant effects of instruction or choice. Similar results were found with the right ventral striatum ROI defined by the regulator group risk analysis. Second, a parametric risk analysis was conducted in the nonregulator group only, leading to the identification of a left ventral striatum ROI defined by this set of participants. A follow-up ANOVA on beta weights extracted for this ROI did not show any significant effects of instruction or choice. Although these null findings should be interpreted with caution given the nature of null findings in fMRI analysis and the small sample size of the nonregulator group, the observations are in line with the nonregulator group's self-reports and behavioral results.

DISCUSSION

Previous studies have highlighted how an array of emotion regulation strategies can be used to alter the intensity of emotional experience (for a review, see Ochsner & Gross, 2008; Green & Malhi, 2006). The present study suggests that cognitive emotion regulation strategies influence subsequent decision-making. Specifically, participants who were successful in their application of an imagery-focused relax regulation strategy (i.e., regulator group) showed a decrease in risky behaviors, in particular, selecting a safe compared with a risky monetary lottery more often. This shift in behavior during decision-making under risk was accompanied by attenuation in BOLD signals in the striatum, a structure previously linked with reward-related processing (Haber & Knutson, 2010; Rangel et al., 2008; Delgado, 2007;

O'Doherty, 2004). In contrast, participants who did not effectively use emotion regulation strategies (i.e., nonregulator group) failed to show behavioral or neural differences during decision-making. Although further research is necessary to fully understand the conditions in which regulation can exert its effect (e.g., individual differences), these findings represent a potential approach to control decision-making under risk that may become compulsive.

The observed relax regulation results support the idea that successful use of cognitive strategies can foster more goal-directed behavior and promote safer, compared with riskier, decision-making. This is in slight contrast with recent studies that suggest successful use of emotion regulation can lead one to reduce loss aversion (Sokol-Hessner et al., 2009) and maximization of rewards (Seo & Barrett, 2007). One potential difference between these studies is the type of strategy employed. For instance, the strategy used by Sokol-Hessner and colleagues (2009) was focused to the particular task at hand, asking participants to place less weight on the outcome of a single decision rather thinking of it as a series of decisions (e.g., an investor's portfolio). In the current experiment, we used a more general imagery-based strategy previously shown to be successful in attenuating the physiological and neural correlates of conditioned fear (Delgado, Nearing, et al., 2008) and the expectation of reward (Delgado, Gillis, et al., 2008). Although both strategies can be considered a form of cognitive control, they might exert different influences in the underlying neural circuitry, as observed in studies comparing reappraisal and distraction strategies during negative emotions (McRae et al., 2010; Kalisch, Wiech, Herrmann, & Dolan, 2006), that could cause different effects in behavior. This is an interesting question for future research examining (a) the effect of different cognitive strategies on subsequent affective behaviors exerted during decision-making and (b) how specific strategies may better suit specific individual differences to have the desired effect on behavior (e.g., promote improved decision-making depending on the context).

Indeed, individual differences with respect to the effective use of the imagery-based strategy were observed in the current experiment as measured by postexperimental ratings. A regulator group was defined by perceived success in applying the relax strategy, whereas a nonregulator group comprised participants who felt they were unable to successfully implement the relax strategy. Differences between these two groups were apparent in subjective ratings (how easy it was to implement strategy), behavioral responses (picking between safe and risky options), and neural signals (striatum responses during decision-making under risk). Of particular interest, the regulator group made fewer risky choices than their counterparts. This behavior was not because of an inherent risk aversion, as both groups risk preferences did not differ according to a paper test assessment (Holt & Laury, 2002). Instead, this shift in behavior could be attributed to the successful use of cognitive strategies.

This behavioral modulation, because of the application of cognitive strategies, was not observed in the group of self-assessed nonregulators. Neither was the modulation of striatum activation by cognitive strategies, consistent with previous studies suggesting that striatum signals during decision-making can correlate with success in task performance (Schonberg, Daw, Joel, & O'Doherty, 2007). It is possible that fatigue contributed to the nonregulators' lack of success at using the imagery regulation, as the task duration was about 40 min. Although the two groups did not differ in any individual measures used in our study, additional research may probe potential differences that allow some to exert better control over their decisions. For instance, are there specific traits or, perhaps more likely, do certain situational factors (e.g., type of strategy attempted, amount of effort applied) determine whether a person will be able to successfully employ regulation? The topic of individual differences in the use of cognitive strategies for regulatory purposes is of great interest currently (e.g., Modinos, Ormel, & Aleman, 2010; Canli, Ferri, & Duman, 2009; Drabant, McRae, Manuck, Hariri, & Gross, 2009; Hariri & Holmes, 2006; Ray et al., 2005; John & Gross, 2004), as research attempts to identify key neural differences between those who exhibit self-control and regulation in their behavior and those who do not. When successful self-controllers (dieters) make food choices, for example, activity in a brain region involved in valuation, namely the ventromedial pFC (Rangel et al., 2008), reflects both taste and health ratings, whereas in non-self-controllers this region only reflects taste information (Hare, Camerer, & Rangel, 2009), highlighting how the ability to exert cognitive control can promote better decision-making (e.g., eating healthy).

The current study found that activity in the ventral striatum of regulators was influenced by the use of cognitive regulation, in accordance with previous research (Staudinger et al., 2009; Delgado, Gillis, et al., 2008). Yet, such studies focused mostly on reward expectations and learning, whereas the current paradigm focuses on the role of emotion regulation on decision-making under risk. The human striatum is often identified during investigations of reward and risky decision-making (Christopoulos et al., 2009; Kuhnen & Knutson, 2005; Matthews et al., 2004), showing greater responses as expected reward values increase (Tom et al., 2007; Yacubian et al., 2006; Knutson & Cooper, 2005) and patterns of activity that suggest processing of reward probabilities (Hsu et al., 2009; Yacubian et al., 2007; Abler, Walter, Erk, Kammerer, & Spitzer, 2006). Building on previous research that suggests expected value-related reward activity in the striatum is modulated by emotion regulation (Staudinger et al., 2009; Delgado, Gillis, et al., 2008), we chose to model reward probability in our analyses to probe the role of the striatum in probability (risk) coding during decision-making and the effects of emotion regulation on this process. In our experiment, the ventral striatum activity during the decision phase was decreased overall for regulators, especially during trials where a risky

choice was made, suggesting that effective regulation can dampen the natural heightened response to decisions under risk.

The BOLD signal observed in the striatum during the decision phase may reflect deliberation with respect to the two options, the choice itself and a reaction to the choice made. Although our model accounted for increasing probability of reward, the magnitude of the options might have influenced neural activity. The expected value of the risky and safe options was equated, but the magnitude of the risky option was always higher. Thus, the increased activity observed in ventral striatum for risky relative to safe choices during Look trials could perhaps be explained by the greater magnitude of the risky option, in turn suggesting that the lack of differentiation between risky and safe choices by the ventral striatum during regulation may indicate disruption of the ability to code reward magnitude. This interpretation is in line with a recent article that found that distance-focused regulation disrupted expected value coding in the ventral striatum, such that during regulation trials ventral striatum activity failed to differentiate high- and low-magnitude cues (Staudinger et al., 2009). Nevertheless, participants who successfully employed cognitive strategies before making financial decisions made fewer risky choices when deliberating between lotteries under risk and showed attenuated BOLD signals in the striatum. Whether emotion regulation specifically affects the coding of the magnitude of potential rewards or the perception of probability (or risk) inherent in the decision process is a topic for further exploration that will continue to advance our understanding of the ability to control emotional responses for adaptive function.

The ventral striatum is an integral component of a corticostriatal circuit involved in motivated behaviors (Haber & Knutson, 2010; Balleine, Delgado, & Hikosaka, 2007; Middleton & Strick, 2002; Alexander & Crutcher, 1990), with important connections with cortical regions, such as OFC and ACC (Haber & Knutson, 2010). Given the connectivity of the ventral striatum, it is plausible that the observed decrease in ventral striatum activity in the regulator group during decision-making after using emotion regulation may have been driven in part by cortical signals. An exploratory analysis revealed that BOLD signals in dorsal cingulate cortex (BA 24) correlated with those from the left ventral striatum, suggesting a potential functional connectivity that may underlie the control of striatum responses during decision-making under risk. Further analysis of the BOLD response within this cingulate region revealed a trend for greater recruitment during the use of regulation strategies than natural responding, which is consistent with findings from previous emotion regulation studies (Staudinger et al., 2009; Eippert et al., 2007; Kim & Hamann, 2007; Phan et al., 2005; Ochsner et al., 2002). Although this analysis is exploratory and, thus, results should be interpreted with caution, the findings point to an enhancement of cortical regions such as the dorsal cingulate cortex during regulation as a potential modulator of striatal responses during decision-making—a topic that will be explored further in future studies.

In addition to the striatum, the effective use of regulation led to attenuation of BOLD signals in the midbrain and insula. The midbrain results are particularly interesting, given that it includes dopaminergic centers that project to the striatum (Haber & Knutson, 2010), and much like the striatum, BOLD signals in the midbrain increase in conjunction with increasing reward values during decision-making under risk (Tom et al., 2007), suggesting that cognitive strategies can have a global impact in the neurocircuitry involved in reward and decision-making. Regulation strategies also had an effect in the insula, a region implicated in risky decision-making (Clark et al., 2008; Kuhnen & Knutson, 2005), perhaps coding different levels of risk (Preuschoff, Quartz, & Bossaerts, 2008). Specifically, a marginal interaction of instruction and choice was seen in the anterior insula, whereas an instruction effect was observed in a more dorsal anterior insula ROI. Future studies may probe anatomical and functional dissociations within the insula as a function of emotion regulation during decision-making.

This study employed two opposite cognitive, imagery-focused regulation strategies, Relax and Excite. No significant shifts in risk-taking or neural activity were associated with the excite strategy. There are several possible explanations for why we did not observe an effect of excite regulation on decision-making, given that relax regulation did influence decision-making. Although the majority of participants rated themselves as successful at visualizing the exciting imagery, they also reported the need to periodically update the exciting images that they thought about, as over time these images lost their potency. Additionally, there were some conflicts between what participants wanted to imagine (e.g., Las Vegas casinos) and the instruction to think of something nontask specific (e.g., a roller coaster). It is possible that the level of excitement achieved with the excite strategy may have been comparable to that which participants experienced when naturally responding to the slot machine cue. If similar affect was associated with the Excite and Look condition, that could underlie the lack of observed differences in risk-taking between these conditions. Future work could address this question by including affect ratings during the task.

Emotion regulation strategies have been traditionally used to control emotional responses induced by stimuli such as pictures, movies, or narratives that evoke negative affect (for a review, see Ochsner & Gross, 2008). More recently, such strategies have also been applied to positive emotions evoked by pictures, food stimuli, or cues that predict reward (Hare et al., 2009; Staudinger et al., 2009; Wang et al., 2009; Delgado, Gillis, et al., 2008; Kim & Hamann, 2007). Here, we extend these findings by focusing on the influence of emotion regulation strategies on decision-making processes and associated neural circuits. This research has applications ranging from simple decisions such as dieting (e.g., Hare et al., 2009) to more complex decisions, where goal-directed and habit learning systems may be at conflict, such as substance

abuse (e.g., Balleine & O'Doherty, 2010; Everitt et al., 2008; Nelson & Killcross, 2006).

Acknowledgments

This work was supported by National Institute on Drug Abuse grants to M.R.D. (DA022998-01 and DA027764-01) and a predoctoral fellowship to L.N.M. (DA025426-01). The authors thank Michael Niznikiewicz for assistance with figures and Elizabeth Tricomi for helpful discussion.

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