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LETTERS

Neural mechanisms mediating optimism bias

Tali Sharot[1,2], Alison M. Riccardi[1], Candace M. Raio[1] & Elizabeth A. Phelps[1]

Humans expect positive events in the future even when there is no evidence to support such expectations. For example, people expect to live longer and be healthier than average[1], they underestimate their likelihood of getting a divorce[1], and overestimate their prospects for success on the job market[2]. We examined how the brain generates this pervasive optimism bias. Here we report that this tendency was related specifically to enhanced activation in the amygdala and in the rostral anterior cingulate cortex when imagining positive future events relative to negative ones, suggesting a key role for areas involved in monitoring emotional salience in mediating the optimism bias. These are the same regions that show irregularities in depression[3], which has been related to pessimism[4]. Across individuals, activity in the rostral anterior cingulate cortex was correlated with trait optimism. The current study highlights how the brain may generate the tendency to engage in the projection of positive future events, suggesting that the effective integration and regulation of emotional and autobiographical information supports the projection of positive future events in healthy individuals, and is related to optimism.

People tend to make overly confident, positive predictions about the future, which are often inaccurate[1,2]. The tendency to expect good things in the future is known as optimism. Extreme optimism can be harmful as it can promote an underestimation of risk and poor planning[5]. In contrast, a pessimistic view is correlated with severity of depression symptoms[3]. A moderate optimistic illusion, however, can motivate adaptive behaviour in the present towards a future goal, and has been related to mental[6] and physical[7] health. How does the healthy brain generate the tendency to create images of positive future events?

It has been suggested that imagining future events demands a system that calls on the past to retrieve pieces of information that are then reconstructed to form representations of possible future scenarios[8,9]. In accordance with this proposal, it has been shown that imagining the future depends on the same neural networks that are active when recalling the past[8,10,11]. One possibility is that in optimists this network is more active when imagining future positive events than negative ones. It is also possible that other brain areas modulate this network in a way that biases it to engage in positive future projections.

To examine the neurobiological basis of optimism we collected functional magnetic resonance imaging (fMRI) data while participants thought of autobiographical events related to a description of a life episode (for example, 'winning an award' or 'the end of a romantic relationship'). The word 'past' or 'future' indicated if they should think of an event that occurred in the past or one that might occur in the future. Trials were classified into positive, negative and neutral according to participants' ratings. The mean number of trials rated as neutral was negligible, and thus all contrasts of interest were conducted between positive and negative trials only.

After scanning, participants rated their memories and projections on six factors[12] related to their subjective experience. The mean scores for these ratings and statistical analysis are presented in Table 1 and Supplementary Table 1. Finally, participants completed the LOT-R (Life Orientation Test-Revised) scale that measures trait optimism[13] (see Methods for details).

As represented in Table 1 and Supplementary Table 1, future positive events were rated as more positive than past positive events, and were imagined to be closer in temporal proximity then future negative events and all past events (Fig. 1a). Negative future events were experienced with a weaker subjective sense of pre-experiencing, and were more likely to be imagined from an outsider viewing in, than positive future events and all past events (Fig. 1b). The more optimistic participants were, as indicated by the LOT-R scores, the more likely they were to expect positive events to happen closer in the future than negative events, and to experience them with a greater sense of pre-experiencing (Fig. 1c, d).

Next we examined the fMRI data to identify the underlying neural mechanisms. Functional regions of interest (ROIs) were identified by contrasting all trials with fixation ($P < 0.00005$, uncorrected). The four regions that survived this threshold (Fig. 2a, b) included the rostral anterior cingulate cortex (rACC, Fig. 2b), extending into the ventral medial prefrontal cortex at a more lenient threshold (see Fig. 3a, c), the posterior cingulate cortex (PCC, Fig. 2b), and the dorsal medial prefrontal cortex (Fig. 2b), all of which have been reported to have a key role in retrieval of autobiographical memory and in imagining future events[8]. The fourth region was the right amygdala, which has been shown to be important for emotion's

Table 1 | Means and statistics for subjective ratings according to trial type

Scale	Future				Past			
	Positive	Negative	*t*-test (*P*)	Correlation with optimism	Positive	Negative	*t*-test (*P*)	Correlation with optimism
Valence	2.44	4.34	<0.001	NS	2.77	4.07	<0.01	NS
Arousal	3.56	3.23	= 0.05	NS	3.50	3.61	NS	NS
Time of event	2.37	3.08	<0.005	<0.005	3.01	3.00	NS	NS
Subjective temporal distance	3.00	3.47	NS	NS	3.33	3.40	NS	NS
Perspective	2.96	3.37	<0.025	NS	2.92	2.91	NS	NS
Reliving or pre-experiencing	3.59	3.07	<0.025	<0.025	3.80	3.85	NS	NS
Vividness	3.66	3.28	NS	NS	3.90	4.19	NS	NS

Valence (1, positive; 6, negative), arousal (1, low; 6, high), time of event (years from present, 1–5), subjective temporal distance (1, near; 6, far), perspective (1, involved; 6, observer), reliving or pre-experiencing (1, low; 6, high) and vividness (1, low; 6, high). NS, not significant.

[1]Department of Psychology, New York University, New York 10003, USA. [2]Wellcome Department of Imaging Neuroscience, Institute of Neurology, University College London, London WC1N 3BG, UK.

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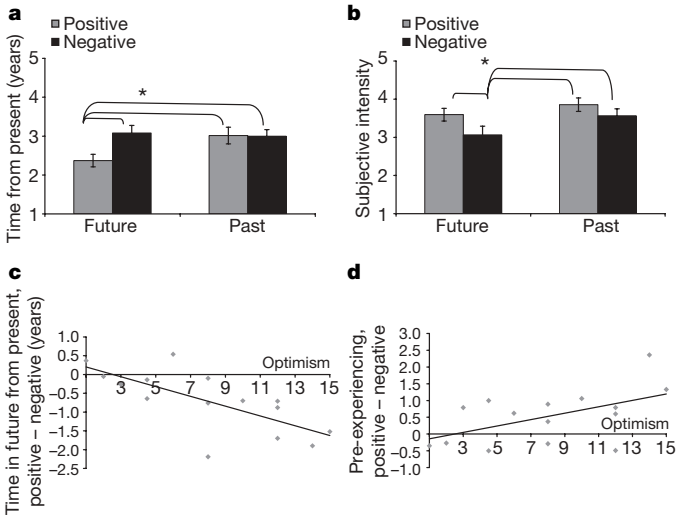

Figure 1 | Optimism related to expected time of event and sense of pre-experiencing future events. **a**, Positive events are perceived to be closer in time to the present than negative future events and all past events. **b**, Negative future events are experienced with a weaker sense of pre-experiencing than positive future events and all past events. **c**, The difference in expected time of event for future positive and negative events correlated with the optimism level defined by ranking participants according to their LOT-R scores ($r = -0.74$, $P < 0.005$). **d**, The difference in pre-experiencing for positive and negative events correlated with trait optimism ($r = 0.58$, $P < 0.025$). $N = 15$; error bars, ±s.e.m.; $^*P < 0.05$.

influence on autobiographical memory[14] (Fig. 2a; the left amygdala was also observed at a more lenient threshold, Fig. 3b, d). Among these ROIs, the blood-oxygenation-level-dependent (BOLD) signal in the amygdala and rACC was reduced when imagining negative future events relative to positive future events and to all past events (Fig. 2c, d). The differences in BOLD signal between positive and negative future events remained significant when controlling for differences in the sense of pre-experiencing (amygdala, $P < 0.01$; rACC, $P < 0.05$). For structural ROI analysis (Supplementary Fig. 1) and exploratory whole-brain analysis, see Supplementary Information.

To examine if these differences were related to optimism across individuals, we identified voxels within the four functional ROIs in which changes in BOLD signal during future positive trials relative to future negative trials were correlated with participants' optimism score on the LOT-R scale (see Supplementary Information for additional analysis and discussion). We found a positive correlation in the rACC (Fig. 2e). No significant correlation with optimism was observed in the other ROIs. Finally, a functional connectivity analysis revealed a strong correlation between activity in the rACC and activity in the amygdala bilaterally while imagining future positive events; this correlation was weaker and less extensive when imagining future negative events (Fig. 2f).

Our behavioural results suggest that, whereas the past is constrained, the future is open to interpretation allowing subjects to distance themselves from possible negative events and move closer toward positive ones. Across individuals, this tendency was associated with trait optimism. The brain imaging findings provide a possible mechanism mediating the behavioural observations.

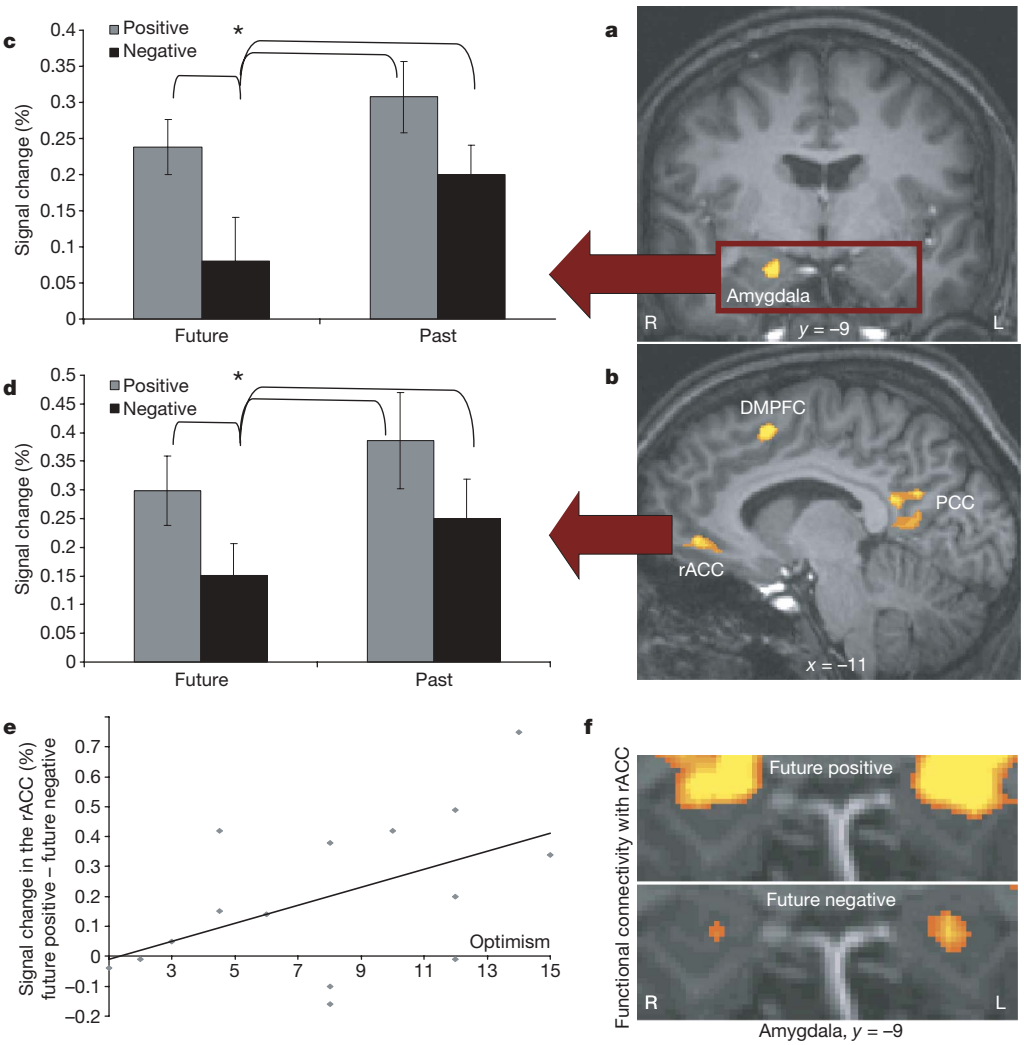

Figure 2 | Activity in the amygdala and rACC and its relation to optimism. ROIs defined by contrasting all trials with fixation (shown at $P < 0.0005$, uncorrected) reveal activity of **a**, the amygdala (Talarich coordinates of peak voxel: 20, −9, −14) and **b**, the rACC (Broadman Area (BA) 32: −11, 42, −1), the PCC (BAs 30 and 31: −4, −47, 19) and the dorsal medial prefrontal cortex (DMPFC; BA 6: −8, 12, 52). BOLD signals in both **c**, the amygdala and **d**, the rACC reduced while imagining negative future events. **e**, BOLD signal in the rACC during future positive events versus future negative events correlated with trait optimism (−9, 39, −2; $r = 0.5$, $P < 0.05$). **f**, Functional connectivity map with rACC as the seed reveals extensive correlation with the amygdala signal during future positive trials, and restricted correlation during future negative trials. The red square in **a** indicates the region shown in **f**. $N = 15$; error bars, ±s.e.m.; $^*P < 0.05$.

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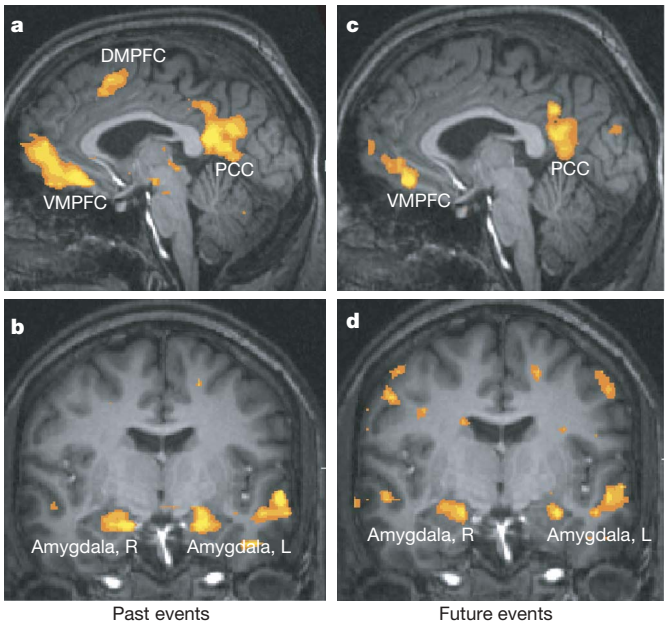

Figure 3 | Brain activity during past and future trials. Regions that emerged when contrasting **a**, **b**, past trials with fixation and **c**, **d**, future trials with fixation at a threshold of $P < 0.005$, uncorrected, reveal engagement of regions shown previously[8] to be involved in autobiographical memory and future projection including ventral medial prefrontal cortex (VMPFC) and the PCC (**a**, **c**), as well as the amygdala bilaterally (**b**, **d**).

Reduced BOLD signal was observed in the amygdala and rACC during imagination of negative future events relative to positive future events and all past events, suggesting that the optimism bias may be related to a reduction in negative future thought.

The amygdala has a documented role in the modulation by emotion of cognitive processes including memory and decision making (for a review, see ref. 15). Our data extend the role of the amygdala to include simulation of future emotional events. Previous studies examining the neural mechanisms underlying imagination of non-emotional future events did not observe amygdala involvement[8,10]. Thus, as in the case of memory, we suggest that the amygdala may be selectively engaged in imagining future emotional events, rather than serving a general function in imagining the future.

The rACC has strong reciprocal connection with the amygdala and other regions that convey emotional and motivational information[16]. It has been implicated in tasks involving self-reflection, such as making positive self-referential judgments[17], reflecting on hopes and dreams[18], indicating preferences[19] and judging the trustworthiness of others[20]. This has caused some researchers to suggest that when information is judged to be self-relevant, activity in the rACC will convey the valence[17]. However, others have suggested a more general role for the rACC in assessing the salience of emotional and motivational information and regulating emotional responses accordingly[21]. Consistent with this notion it has been shown that the rACC's response to positive and negative stimuli reflects situational specificity. For example, both the rACC and amygdala were more sensitive to positive stimuli in subjects that focused on obtaining goals (promotional context) and to negative stimuli in subjects that focused on avoiding failure (prevention context)[22]. Furthermore, changes in rACC activity have been related to extinction of fear conditioning[23], and to reduced anxiety during shock expectancy[24]; this possibly indicates diminished salience of negative stimuli that may consequently lower amygdala activity[23].

Consistent with these previous studies, we suggest that in the current study the rACC is tracking the subjective salience of the stimuli by assessing emotional, motivational and autobiographical information, and possibly by regulating such signals. This suggestion is supported by the strong functional connectivity observed between the rACC and amygdala during imagination of positive future events. In addition, individual differences in trait optimism were related to the relative level of rACC engagement when imagining positive future scenarios versus negative ones. We speculate that rACC activity during imagination of future events reflects a self-regulatory focus that underlies a bias in attention and vigilance towards positive future events and away from negative ones, modulating engagement of other regions that provide emotional and autobiographical information that is processed and recombined to construct future scenarios.

These findings may provide insight to the mechanisms underlying depression. Depressive symptoms are associated with pessimism[4] and with difficulties in creating detailed images of future events[25]. It has been suggested that malfunction of a neural pathway incorporating the rACC and the amygdala may cause depression by leading to decreased regulatory affects of the rACC over the amygdala and other regions involved in emotional processing[3]. Future studies are needed to determine whether these abnormalities are related directly to the breakdown of optimism in depression, specifically because it relates to the way in which depressed patients imagine future events.

One should note that when comparing past and future trials we are also comparing imagining and remembering. Thus, our data cannot indicate whether the positivity bias is a function of time (that is, it will emerge only when thinking about the future) or whether it reflects a tendency to engage in positive thought when not constrained by reality. We speculate that the difference is not between past and future, although in practice the optimism bias manifests itself in thoughts of the future because the absence of factual constraints leaves plenty of room to alter expectations.

Expecting positive events, and generating compelling mental images of such events, may serve an adaptive function by motivating behaviour in the present towards a future goal. We do not suggest that simulating negative events is not important for survival. However, pondering on such events may interfere with daily activities by promoting negative effects such as anxiety and depression. The current study highlights how the brain may generate the tendency to engage in the projection of positive future events, suggesting that the rACC modulates activity in brain areas that are involved in emotional processing and autobiographical retrieval to create positive images of the future.

METHODS SUMMARY

Functional MRI images were collected from participants while they thought of autobiographical events related to a description of a life episode that appeared on screen for 14 s. Either the word 'past' or 'future' indicated if they should think of an event that occurred in the past or that might occur in the future. The participants were instructed to press a button once the memory or projection was beginning to form in their mind, and again when they finished elaborating on it. They then had 2 s to rate the memory or projection for emotional arousal and 2 s to rate it for valence. There were 80 trials that were classified into positive, negative or neutral according to the participants' ratings.

After scanning, participants rated their memories or projections on six factors[12] related to their subjective experience, and completed the LOT-R scale that measures trait optimism[13]. Participants were ranked according to their optimism score on the LOT-R scale. These optimism rankings were correlated with the difference in scores (future positive minus future negative) on the behavioural scales.

For each participant a time series was created indicating the temporal position of the different trial types triggered from the participant's first button press. Functional ROIs were identified by contrasting all trials with fixation ($P < 0.00005$, uncorrected) using random effects GLM (General Linear Model) on the data of all participants. The time courses of activation were extracted from these regions for each trial type and participant for statistical analysis. Next, we identified voxels within the ROIs in which changes in BOLD signal during future positive trials relative to future negative trials were correlated with the LOT-R scores. Additionally, functional connectivity maps[26] were created for the different trial types (False Discovery Rate (FDR) correction threshold at $t = 5.5$).

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Supplementary Information is linked to the online version of the paper at www.nature.com/nature.

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Author Contributions T.S. designed the study. T.S. and E.A.P. interpreted the data and wrote the paper. T.S. and A.M.R. developed stimuli, gathered behavioural pilot data, and conducted behavioural data analysis. T.S. gathered fMRI data. T.S. conducted neuroimaging analyses with the help of A.M.R. and C.M.R., and with advice of E.A.P. Whole-brain exploratory analysis was conducted by C.M.R.

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METHODS

Participants. Participants (18) were recruited through posted advertisements. Three were eliminated from the analysis because of either excessive head movement or spikes identified in the fMRI data. The remaining 15 participants were included in the analysis (7 males, 8 females; mean age, 23.4 yr; range, 18–36 yr). Before scanning, participants completed a screening form for significant medical conditions. All participants gave informed consent and were paid for their participation.

Stimuli. Stimuli consisted of 80 short descriptions of possible life episodes (Supplementary Information). The order and condition in which episodes were presented were random. Because participants had a tendency to generate positive events, we needed to provide more negative and neutral life episodes to obtain an equal number of trials rated as positive and negative.

Procedure. Before the scanning session, participants went through four practice trials. The session began with a short structural scan, followed by four functional scans (10 min each), each consisting of 20 trials of 30 s. Finally, an additional longer structural scan was performed. Stimuli were presented by means of a mirror mounted on the head coil. In each trial, a description of a possible life episode and the word indicating the condition of the trial (either 'past' or 'future') appeared for 14 s. The participants were instructed to press a button once a mental memory or projection was beginning to form in their mind, and again if they finished elaborating on it before the end of the trial. The participant then had 2 s to rate the memory or projection for emotional arousal (1, not arousing; 2, somewhat arousing; 3, highly arousing) and 2 s to rate it for valence (1, positive; 2, neutral; 3, negative). Finally, a fixation cross was presented for 12 s. If the participant did not press the button to indicate that they were thinking of a specific memory or projection, or did not indicate arousal and/or valence by pressing the button box, that trial was excluded from the final data analysis. The number of trials rated as positive and negative did not differ for future or past conditions. Reaction times, indicating when a mental memory or projection was beginning to form in the participants' mind, did not differ for the different trial types (range of means: 2.9–3.6 s).

After the scanning session, participants were presented with the same trials again on a computer screen, and were asked to rate their memories or projections on six scales adapted from a previous study[12]: vividness, sense of reliving or pre-experiencing, estimation of the time of the event, subjective temporal distance from the event, perspective (involved or observer), arousal and valence. Finally, participants completed the LOT-R scale that measures trait optimism–pessimism on a scale from 0 (pessimistic) to 24 (optimistic)[13]. Participants were generally optimistic; the mean optimism score was 17.76.

Behavioural analysis. Participants were ranked according to their optimism score on the LOT-R scale from the most optimistic to the least optimistic. These optimism rankings were correlated with the difference scores (future positive minus future negative) on the behavioural scales.

MRI scanning and data analysis. The study was conducted at the NYU Center for Brain Imaging using a 3T Siemens Allegra scanner and a Siemens head coil. Anatomical images were acquired using MPRage scans, followed by 3-mm-thick axial slices (parallel to the anterior cingulate–posterior cingulate plane).

Positioning of the slices was based on an AAscout sequence. Functional scans used a gradient echo sequence: TR (time of repetition) = 2 s, TE (time of echo) = 25 ms, FA (flip angle) = 90, matrix = 64 × 64, FOV (field of view) = 192 mm, slice thickness = 3 mm. A total of 39 axial slices parallel to the AC–PC plane were sampled for whole-brain coverage. The in-plane resolution was 3 mm × 3 mm. Imaging data were analysed using Brain Voyager software (QX, version 1.7).

Data were temporally and spatially smoothed (4 mm full-width at half-maximum) and motion-corrected. Individual data were transformed into Talairach space for group analysis. For each participant, a time series was created indicating the temporal position of the different trial types triggered from the participant's first button press to the onset of the rating scale.

Trial types were classified into six groups according to the participants' arousal and valence ratings during the fMRI scanning: future positive, future negative, future neutral, past positive, past negative and past neutral. Negative events were those receiving high (3) or medium (2) arousal rating and negative valence (3). Positive events were those receiving high (3) or medium (2) arousal rating and positive valence (1). Neutral events were those receiving low arousal rating (1) and neutral valence (2). Trials receiving any other combination of responses could not be characterized in either group and were not included in the analysis. The seventh trial type was fixation.

Functional ROIs were identified by contrasting all trials with fixation ($P < 0.00005$, uncorrected) using random effects GLM on the data of all participants. We extracted the time course of activation from these regions for the different trial types for each participant. The average percentage signal change from 6 s to 8 s after the participant's first button press in these ROIs were calculated for each trial type and participant. Statistical tests were performed on these values. Within these functional ROIs, we conducted a voxel-wise analysis of covariance contrasting future positive trials with future negative trials using the LOT-R optimism score as a covariate ($P < 0.05$). In addition, a priori regions of interest—the right and left amygdala—were identified according to landmarks described previously[27]. Extraction of time courses and statistical analysis was done in the same manner as for the functional ROIs.

Functional connectivity analysis[26] was conducted using the rACC ROI as a seed. Maps were created to identify voxels where BOLD signal was temporally correlated with the seed during future positive trials and during future negative trials (FDR correction threshold at $t = 5.5$).

To identify other voxels in the brain that showed stronger BOLD responses during one trial type than the other, we conducted a whole-brain exploratory analysis on group data using a random effects GLM (at $P < 0.001$, uncorrected; >10 contiguous voxels 1 mm^3).

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