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Neural correlates of envisioning emotional events in the near and far future

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Abstract

Being able to envision emotional events that might happen in the future has a clear adaptive value. This study addressed the functional neuroanatomy of this process and investigated whether it is modulated by temporal distance. Participants imagined positive and negative events pertaining to the near future or far future while their brain activity was measured with fMRI. The results demonstrate that the anterior part of the ventromedial prefrontal cortex (vmPFC) was more active in envisioning emotional events in the far future than in the near future, whereas the caudate nucleus was engaged in envisioning emotional (especially positive) situations in the near future. We argue that the anterior part of the vmPFC might assign emotional values to mental representations of future events that pertain to long-term goals. On the other hand, the caudate might support more concrete simulations of action plans to achieve rewarding situations in the near future.

Introduction

A fundamental aspect of human consciousness relates to the ability to temporarily withdraw attention from the immediate environment to mentally simulate episodes that might happen in the future (Atance and O'Neill, 2001; Buckner and Carroll, 2007; Morin, 2006; Suddendorf and Corballis, 2007; Tulving, 2005). This underlies the human capacity to foresee, plan, and shape virtually any specific future event, which has a clear adaptive value, enabling one to act flexibly in the present to increase future chances of survival (Suddendorf and Corballis, 2007). Affective states associated with the anticipation of future outcomes play a major role in this process, with neural systems carrying emotional signals providing valuable implicit or explicit knowledge for making decisions that are advantageous in the long-term (Bechara and Damasio, 2005). Converging evidence from cognitive psychology, developmental psychology, neuropsychology, and psychopathology indicates that mental simulations of future events rely on episodic memory (Addis et al., in press; Atance and Meltzoff, 2005; D'Argembeau et al., in press; D'Argembeau and Van der Linden, 2004, 2006; Hassabis et al., 2007; Klein et al., 2002; Spreng and Levine, 2006; Suddendorf and Busby, 2005; Szpunar and McDermott, in press; Tulving, 2005; Williams et al., 1996) and recruit multiple cognitive processes, such as scene construction (i.e., the retrieval and integration of elements of previous experiences into a coherent event) (Hassabis and Maguire, 2007; Schacter and Addis, 2007), a subjective sense of time and a reference to the self (Buckner and Carroll, 2007; Tulving, 2005). Consistent with this view, recent functional neuroimaging studies have highlighted the engagement of a common neural network consisting of the ventromedial prefrontal cortex (vmPFC; Brodmann's area (BA) 10, 11), medial temporal lobe (hippocampus and parahippocampal gyrus), and medial posterior regions (posterior cingulate and retrosplenial cortex) when participants are engaged in imagining future events and

remembering past events (Addis et al., 2007; Botzung et al., in press; Hassabis and Maguire, 2007; Okuda et al., 2003; Szpunar et al., 2007).

Despite their important role in future decision, few studies have directly investigated the neural substrates of emotion signals when people are consciously envisioning future emotional scenarios. Current evidence from lesion studies points to the vmPFC as a critical neural structure for triggering the affective/emotional signals associated with the imagination of future outcomes. In particular, studies that have used the Iowa Gambling Task indicate that patients with damage to the vmPFC fail to generate emotional signals in anticipation of future events, which led them to make decisions that are disadvantageous in the long-term (Bechara et al., 1997; Bechara et al., 2000). A recent fMRI study suggests that the vmPFC also participates in the conscious mental simulation of future emotional events (Sharot et al., in press). Participants were asked to generate future events in response to a series of cues describing positive and negative life episodes (e.g., ‘winning an award’ or ‘the end of a romantic relationship’). Thinking of these positive and negative future events led to increased activity in the vmPFC, posterior cingulate cortex, and amygdala, compared to fixation. Furthermore, the vmPFC was more engaged when envisioning positive future events relative to negative future events, a difference which correlated with participants’ trait optimism. Sharot et al. suggest that the vmPFC plays a role in tracking the emotional salience of future events and biases attention towards positive rather than negative future events, thereby fostering optimism.

What is less understood is how the neural substrates of mental simulations of future emotional events are modulated by the perceived temporal distance of the future episodes. Throughout evolution, humans have developed greater capacity to envision events that are far more distant in the future (Leary, 2004; Suddendorf and Corballis, 2007) and it has been argued that the representation of emotional outcomes might be supported by distinct neural

systems for the near and far future (Bechara, 2005; Bechara and Damasio, 2005). According to this hypothesis, the anterior part of the vmPFC (BA 10, 11) is a critical neural structure for triggering the affective/emotional signals associated with long-term outcomes, whereas a more posterior neural system (including the posterior part of vmPFC (e.g., BA 25), the amygdala, and the striatum) is involved in triggering the affective/emotional signals of immediate outcomes. Three lines of research are in keeping with such a distinction. First, it has been found that thinking of the far future (the next several years) compared to thinking of the near future (the next few days) engages the anterior vmPFC (BA 10, 11) (Okuda et al., 2003), and patients with damage to this region demonstrate a severe shortening in their personal future time perspective (Fellows and Farah, 2005). Second, research in animals and humans indicates that the anticipation of immediate emotional outcomes (especially rewards) engages the striatum, the amygdala, and the orbitofrontal cortex (for reviews, see Knutson and Cooper, 2005; O'Doherty, 2004; Schultz, 2000). Third, functional neuroimaging studies of time discounting for rewards show that activation of the striatum and posterior vmPFC is greater for choices between an immediate reward and a delayed reward than for choices between two delayed rewards (McClure et al., 2004; McClure et al., 2007). However, to our knowledge, no study has examined whether the anterior-posterior distinction also exists when comparing consciously simulated emotional events in the near and in the far future.

The primary goal of this study was to further explore the neural substrates of conscious mental simulations of future emotional events and, more specifically, to investigate whether distinct brain regions are engaged depending on the perceived temporal distance of the future episodes. Using functional magnetic resonance imaging (fMRI), we directly compared the brain regions recruited for imagining far and near future emotional events. In a pre-scan interview session, participants were asked to generate a list of positive and negative events that might happen to them in the near future (i.e., in the next few days or weeks) or in

the far future (i.e., in at least one year). They were also asked to think of some routine activities (e.g., showering), which were used to control for the process of scene construction (i.e., the retrieval and integration of elements of previous experiences into a coherent scene) (Hassabis and Maguire, 2007). For each future event and routine activity, participants were asked to write a short cue that summarizes the essence of the event and to rate each event for vividness/amount of details, temporal distance, and emotional valence on a 7-point rating scale. The next day, participants were presented with the cues and were asked to mentally simulate the corresponding future events and routine activities while their brain activity was measured with fMRI. Participants were required to imagine each event for 15 seconds, and they were asked to rate their feeling of mentally experiencing the event by means of a 4-point rating scale after the 15 second period. In line with previous studies (Addis et al., 2007; Botzung et al., in press; Hassabis and Maguire, 2007; Okuda et al., 2003; Sharot et al., in press; Szpunar et al., 2007), we expected to observe activations in the vmPFC and medial posterior regions (posterior cingulate/retrosplenial cortex) when participants were envisioning near and far future events as compared to routine activities. We further hypothesized that the neural substrates of envisioning future emotional events would be modulated by temporal distance, that is, mentally simulating emotional events that are far in the future would engage the anterior vmPFC to a greater extent, whereas simulating emotional events in the near future would engage more posterior regions, such as the posterior vmPFC and/or the striatum.

Materials and methods

Participants

Twelve healthy right-handed young adults (7 women, 5 men; mean age: 25 years, range: 22-28 years) were recruited from the University of Southern California (USC) campus. They all

gave written informed consent and were paid for their participation. All experimental procedures had prior approval by the Institutional Review Board at USC.

Tasks description and procedure

One day before the fMRI session, subjects participated in a pre-scan interview in a quiet room of our laboratory. They were asked to imagine four types of future events: positive events that might happen to them in the near future (NearPos), negative events that might happen to them in the near future (NearNeg), positive events that might happen to them in the far future (FarPos), and negative events that might happen to them in the far future (FarNeg). The near future was defined as the next few days or weeks (with a maximum of a month), whereas the far future corresponded to events occurring in at least one year from now. A positive event was defined as something participants are looking forward to, whereas a negative event was defined as an experience they would prefer to avoid. Participants had to imagine five events of each type and for each type of event, they had to envision episodes related to some broad categories: 2 events related to work or school, 2 events related to family or friends, and 1 event related to a romantic relationship; these categories were used because they are the most frequently reported when people were asked to envision positive and negative future events (D'Argembeau and Van der Linden, 2004). Within these broad categories, participants were free to imagine any event they wanted, provided that it consisted of a specific episode (i.e., an event happening at a particular place and time and lasting no longer than a day) that might plausibly happen to them in the specified time period. For each future event, participants were asked to generate a short sentence summarizing the content of the event, which was used as a cue for the fMRI session. They were also asked to take a few seconds to imagine the event in as much detail as possible and to consider, in particular, when and where the event would occur, the persons and objects that would be present, the actions, and their feelings. Then,

they rated their imaginations on a 7-point rating scale that assessed vividness/amount of details (1 = vague with no details, 7 = vivid and highly detailed), subjective feeling of temporal distance (1 = the event feels very close in time, 7 = the event feels very far away), and emotional valence (-3 = very negative, 0 = neutral, +3 = very positive).

During the pre-scan interview, participants were also asked to select five routine activities, which were used as control tasks in the fMRI session. These routine activities were defined as repetitive tasks that participants perform everyday (or at least several times a week) and that are emotionally neutral (e.g., taking a shower, washing the dishes). They were asked to imagine each routine activity in as much detail as possible (i.e., to think of where the activity takes place, the persons and objects that are present, and the actions) and it was further specified that they should consider these activities in a general way (i.e., considering how the activity typically unfolds instead of considering a particular occasion when they did this activity). This control task was selected because it involved processes of scene construction (i.e., the retrieval and integration of elements of previous experiences into a coherent scene; Hassabis & Maguire, 2007) that are similar to the imagination of future events, but had no temporal or emotional components. For each routine activity, participants also rated their representation for vividness/amount of details (1 = vague with no details, 7 = vivid and highly detailed) and emotional valence (-3 = very negative, 0 = neutral, +3 = very positive).

During the fMRI session, participants had to think about the future events and daily routines they imagined the day before. Each event was cued by a slide that contained a written description of the event (i.e., near future, far future, or daily routine) and the cue created by the participants (e.g., “Near future: Concert with Jen on Saturday,” “Far future: Dad has a stroke in my presence,” “Daily routine: Getting dressed”). For future events, participants were instructed to project themselves in each specific event, to imagine it in as much detail as

possible, and to consider, in particular, the time period when the event would happen, the location where it would occur, the persons and/or objects that would be present, the actions, and their feelings. For the routine activities, they were told to imagine themselves doing each activity in as much detail as possible and to consider where the activity occurs, the persons and/or objects that are present, and the actions. It was further specified that they should consider each activity as it typically unfolds (instead of remembering a particular occasion when they did this activity).

Each trial consisted of the following sequence of events: (1) cue presentation: visual presentation of the cue slide; participants were asked to read the cue in order to identify the event and then to close their eyes and to press a button to indicate that they began to imagine the event (a beep was presented to confirm button press). This stage was self-paced and could take up to 5 seconds. (2) imagination phase: this stage started right after the button press; participants imagined the event with eyes closed for 15 s. (3) rating: after 15 s, participants heard a beep indicating that they need to open their eyes and to rate the extent to which they had the feeling of mentally experiencing the event; a 4-point rating scale was displayed for 5 s on the screen, during which participants had to make their judgment (1 = not at all, 4 = completely). Trials were separated by a rest period which was jittered between 2 to 10s (exponential distribution with a mean of 5 s), during which a fixation cross was presented. To reduce the interference effect of scanner noise on participants' imagination in the beginning of the scan, participants completed one practice run while structural images were acquired. After that, three functional runs were acquired for each participant. Each run consisted of the same 25 cues (5 per event category), with the order randomized from run to run. In total, each event was thus imagined four times. fMRI data were collected for each event three times. It was specified that participants were not required to imagine exactly the same things each time they were presented with a particular cue (e.g., they might think of additional details concerning

the event the second time they imagine it), the important point being that, on each trial, they were required to try to project themselves into the event in as much detail as possible in order to mentally experience the situation. Each run lasted between 10.8 and 12.5 min, depending on the time taken by participants to identify each event and to press the button to indicate they begin envisioning it. Interviews conducted immediately after the fMRI session indicated that participants were able to project themselves into the future events each time the relevant cue was presented (i.e., they did not simply remember the simulations they had previously made during the pre-scan interview or during the previous run). The post-scan interviews also confirmed that participants were able to think of routine activities in a temporally decontextualized way (i.e., without remembering specific instances when they did this activity).

MRI acquisition

MRI recording was performed using a standard birdcage head-coil on a Siemens 3T MAGNETOM Trio MRI system with TIM housed in the Dana and David Dornsife Cognitive Neuroscience Imaging Center at USC. Participants lay supine on a scanner bed, and viewed visual stimuli back-projected onto a screen through a mirror attached onto the head coil. Foam pads were used to minimize head motion.

Blood-oxygenation-level-dependent (BOLD) signal were measured with a T2*-weighted echo-planar imaging (EPI) sequence (TR=2000 ms, TE=25 ms, flip angle=90°, FOV=192 × 192 mm, in-plane resolution=64 × 64 pixels or 3 × 3 mm). Thirty-one interlaced axial slices, with thickness of 3.5 mm (no gap), were acquired to cover the whole brain. For each participant, three functional runs were collected, each of which lasted between 10.8 and 12.5 min (between 324 and 375 volumes). For each participant, high resolution (1 x 1 x 1

mm³) anatomical images were obtained with a T1-weighted 3D MPRAGE sequence (TI=900 ms, TR=2070 ms, TE=4.13 ms, flip angle = 7°). The whole session lasted about 1 hour.

fMRI analyses

Imaging data were pre-processed and analyzed using SPM5 (Wellcome Department of Imaging Neuroscience; www.fil.ion.ucl.ac.uk/spm). Functional images were realigned and unwarped, normalized directly to the MNI EPI template (voxel size = 3 × 3 × 3 mm), and spatially smoothed with a Gaussian kernel with full-width at half maximum (FWHM) of 8 mm.

For each participant, BOLD responses were estimated using a general linear model. For each trial, the cue presentation, imagination phase, and rating were modelled separately. All of the five conditions were included in the model. The canonical SPM HRF was used, with time derivatives. A high pass filter was implemented using a cut-off period of 128 s in order to remove the low-frequency drifts from the time series. Serial autocorrelations were accounted for using an autoregressive AR(1) model. For each individual participant, we first contrasted the imagination phase of near future events with the imagination phase of routine activities [(NearPos + NearNeg) – Control] and the imagination phase of far future events with the imagination phase of routine activities (FarPos + FarNeg) – Control]. Then, for future events, we examined the main effect of temporal distance [(FarPos + FarNeg) – (NearPos + NearNeg)], the main effect of valence [(NearPos + FarPos) – (NearNeg + FarNeg)], and their interaction [(NearPos – NearNeg) – (FarPos – FarNeg)] by defining the proper contrasts for each participant. The resulting contrasts were entered into second-level random-effects analyses (one-sample *t*-tests) in order to compute group effects. For each a priori region of interest (ROI), statistical inferences were performed at the voxel level at $p < .05$ corrected for multiple comparisons over entire search volume of the ROI using random

field theory. Volumes of interest corresponding to the vmPFC (defined as z coordinate ≤ 0 mm) and striatal regions (caudate nucleus, putamen, and nucleus accumbens) were anatomically defined using the automated anatomical labelling map (AAL) (Tzourio-Mazoyer et al., 2002) and were used for small volume corrections. For other brain regions, we report clusters with more than 10 voxels (3 X 3 X 3 mm) activated above a threshold of $p < .001$ (uncorrected). Finally, ROI analyses were also conducted to quantify the activations within each region. Functional ROIs were defined as 6 mm sphere around the local maxima based on the group averaged results. We calculated for each participant and each ROI the mean effect size for each future task relative to the control task. These values were then submitted to 2 (valence) X 2 (temporal distance) ANOVAs.

Results

Behavioral data

Pre-scan interview

The mean ratings for vividness, feelings of temporal distance, and valence obtained during the pre-scan interview are shown in Table 1. One-way ANOVA showed that vividness ratings differed as a function of event type ($F_{(4, 44)} = 12.70, p < .001$), and follow-up comparisons indicated that representations of routine activities were rated as being more vivid than representations of each type of future events (all $ps < .001$). There was also an effect of event type for valence ($F_{(4, 44)} = 629.17, p < .001$); follow-up comparisons showed that compared to the routine activities, the ratings of valence of the imagined positive future events were indeed more positive (both $ps < .001$), and the negative future events were indeed more negative (both $ps < .001$).

Focusing on the future events, temporal distance (far vs. near) by valence (positive vs. negative) ANOVA was conducted for each type of ratings. For vividness, the effect of

temporal distance and valence were not significant, nor was the interaction between the two factors (all $ps > .21$). For feelings of temporal distance, the ANOVA yielded an effect of temporal distance ($F_{(1, 11)} = 275.77, p < .0001$), confirming that far future events felt more distant in time than near future events; there was no effect of valence, nor interaction (all $ps > .10$). For ratings of valence, there was a main effect of valence ($F_{(1, 11)} = 1409.63, p < .0001$) and an interaction between valence and temporal distance ($F_{(1, 11)} = 13.28, p = .003$), indicating that positive and negative events received higher valence ratings for the far future than for the near future.

fMRI session

Initial analyses did not reveal any effect of repetition of imaginations across runs or any interaction involving this factor, so data from the three functional runs are combined in the reported analyses. The feeling of experiencing the events during the fMRI session differed as a function of the type of events ($F_{(4, 44)} = 9.18, p < .001$; see Table 1 for means and SD), and follow-up comparisons showed that routine activities received higher ratings compared to each type of future events (all $ps < .05$), except near positive events ($p = .44$). For future events, a 2 (temporal distance) X 2 (valence) ANOVA yielded a main effect of temporal distance ($F_{(1, 11)} = 23.63, p < .001$) and a main effect of valence ($F_{(1, 11)} = 10.03, p < .01$), showing that ratings were higher for the near future than for the far future, and higher for positive events than for negative events; the interaction was not significant ($F_{(1, 11)} = 0.39, p = .54$).

The time taken to identify each event (as assessed by the button press) differed as a function of the type of events ($F_{(4, 44)} = 6.05, p < .001$); follow-up comparisons showed that routine activities were identified more quickly than each type of future events (all $ps < .05$;

see Table 1 for means and SD). For future events, a 2 (temporal distance) X 2 (valence) ANOVA did not reveal any significant main effect or interaction (all $F_{(1, 11)} < 2.21$, $ps > .16$).

fMRI data

Near and far future events versus routine activities

Imagining emotional events in the near and far future was associated with similar activation patterns in medial prefrontal and medial posterior regions, relative to imagining routine activities (Figure 1 and Table 2). More specifically, for both the near and the far future, increased activations were detected in the vmPFC (encompassing BA 10 and 11), the dorsomedial PFC (BA 9/10) and the posterior cingulate/retrosplenial cortex. Increases in activation associated with imagining near and far future events were also detected in the inferior temporal gyrus and the temporoparietal junction (see Table 2 for MNI coordinates and Z values). A conjunction analysis (i.e., [Near future > control AND Far future > control]) confirmed that these regions were commonly engaged by near and far future events (see Figure 1 and Table 2).

Effects of temporal distance and valence

When directly comparing the brain regions recruited for imagining emotional events in the near and far future, we found that the ventral part of the anterior vmPFC (BA 11) was more active when envisioning the far future (Figure 2 and Table 3). Imagining the far versus near future also led to increased activations in the left middle temporal gyrus, the left and right inferior temporal gyrus, and the left inferior frontal gyrus (see Table 3 for MNI coordinates and Z values). By contrast, the left caudate nucleus was more active when imagining emotional events in the near future than in the far future (Figure 2 and Table 3).

We also explored the effect of valence by comparing the brain regions recruited for imagining positive and negative future events. Imagining positive versus negative events was associated with activation in the vmPFC (BA 10), in a region more dorsal than the region detected for the effect of temporal distance (Figure 3 and Table 4). Envisioning positive events also led to increased activations in the left caudate nucleus, the left middle/superior frontal gyrus, the posterior cingulate/retrosplenial cortex, the lateral temporal cortex (in the left middle temporal gyrus and the left and right inferior temporal gyrus), the left and right temporoparietal junction, the left hippocampus, the right parahippocampal gyrus, the anterior cingulate, and the lingual gyrus (see Table 4 for MNI coordinates and Z values). Imagining negative events relative to positive events did not lead to significant activation. The temporal distance X valence interaction did not reveal any significant activation either.

ROI results

For each region of interest (ROI), we conducted a 2 X 2 ANOVA on the mean effect size to further evaluate the main effects of temporal distance and valence, and their interaction (see Material and methods for details). For the ventral part of anterior vmPFC (BA 11; peak activation at $x = -3, y = 51, z = -18$), the ANOVA showed a main effect of temporal distance ($F_{(1, 11)} = 36.4, p < .001$) and no effect of valence ($F_{(1, 11)} = 1.99, p = .19$), nor interaction ($F_{(1, 11)} = 0.03, p = .86$). This result provides further evidence that the recruitment of this part of the vmPFC was specifically related to temporal distance (see Figure 2(a), right panel, for effect sizes). For the more dorsal part of anterior vmPFC (BA 10; peak activation at $x = 0, y = 57, z = -3$), the ANOVA showed a main effect of valence ($F_{(1, 11)} = 32.2, p < .001$) and no effect of temporal distance ($F_{(1, 11)} = 0.37, p = .56$), nor interaction ($F_{(1, 11)} = 0.06, p = .81$), indicating that the recruitment of this part of the vmPFC was specifically related to valence (see Figure 3, right panel, for effect sizes). Finally, the left caudate nucleus (peak activation at $x = -12, y =$

21, $z = -3$) is not only involved in imagining the near versus far future ($F_{(1, 11)} = 33.63, p < .001$), but is also recruited to a greater extent when envisioning positive compared to negative future events ($F_{(1, 11)} = 10.30, p = .008$); there is no interaction ($F_{(1, 11)} = 2.38, p = .15$) (see Figure 2(b), right panel, for effect sizes).

Discussion

This study addressed the functional neuroanatomy of mental simulations of future emotional events and investigated whether it is modulated by temporal distance. We found that envisioning near and far future events recruited the vmPFC, the dorsomedial PFC, medial posterior regions (posterior cingulate/retrosplenial cortex), the lateral temporal cortex and the temporoparietal junction to a greater extent than imagining routine activities. More importantly, this study demonstrates that part of the neural circuit engaged when envisioning the future is modulated by the temporal distance of the events. That is, activation of the ventral part of anterior vmPFC (BA 11) was greater when envisioning emotional events in the far future, whereas the left caudate nucleus responded more to emotional events in the near future. Neural substrates of envisioning the future were also modulated by emotional valence, with the imagination of positive events (relative to negative events) leading to activations in the dorsal part of anterior vmPFC (BA 10), the left dorsolateral PFC, the left caudate nucleus, the posterior cingulate/retrosplenial cortex, the lateral temporal cortex, the temporoparietal junction, the left hippocampus, the right parahippocampal gyrus, the anterior cingulate, and the lingual gyrus.

The engagement of the vmPFC and medial posterior regions when envisioning future events versus routine activities is in agreement with previous studies of episodic future thinking (Addis et al., 2007; Botzung et al., in press; Hassabis and Maguire, 2007; Okuda et al., 2003; Sharot et al., in press; Szpunar et al., 2007). The vmPFC (especially BA 10) has

been associated with self-referential processing, both in the context of personality trait judgments (D'Argembeau et al., 2005, 2007; Johnson et al., 2002; Kelley et al., 2002; Northoff et al., 2006) and autobiographical memory (Cabeza and St Jacques, 2007; Gilboa, 2004; Svoboda et al., 2006). The posterior cingulate/retrosplenial cortex is thought to play a role in putting self-referential information in a temporal and spatial context (Northoff et al., 2006) and might also mediate interactions between emotion and episodic memory (Maddock, 1999). Activation of the vmPFC and posterior cingulate/retrosplenial cortex in this study might therefore reveal more self-reflection, a higher emotional involvement, and/or an increased subjective sense of time when envisioning future events compared to routine activities. Alternatively, some authors have argued that the primary role of medial prefrontal and posterior regions is related to the process of scene construction (i.e., the retrieval and integration of elements of previous experiences into a coherent scene) (Hassabis and Maguire, 2007). In this study, both the future tasks and the control task involved scene construction and mental images of routine activities were actually rated as containing more details than images of future events. We are thus inclined to think that activation of the vmPFC and the posterior cingulate/retrosplenial cortex cannot be entirely explained by the process of scene construction. It remains possible, however, that scene construction was easier for routine activities than for future events. It should also be noted that, contrary to some previous studies (e.g., Addis et al., 2007; Okuda et al., 2003), we did not find activation of the medial temporal lobe when contrasting future events with routine activities. This discrepancy between studies is likely due to differences in the nature of comparison tasks. As already mentioned, the imagination of routine activities required the retrieval and integration of pieces of information to construct a coherent scene, which is thought to rely on the hippocampus (Hassabis & Maguire, 2007; Schacter & Addis, 2007). Thus, the future tasks and the comparison task used in the current study both involved a high degree of scene construction, which might have

subtracted out hippocampal activation. On the other hand, the control tasks used in previous studies (e.g., semantic retrieval) relied less on scene construction processes.

A key finding of this study is that imagining emotional events in the far future led to increased activations in the ventral part of anterior vmPFC (BA 11), the lateral temporal cortex and the left inferior frontal gyrus, compared to imagining emotional events in the near future. Although representations of future events probably contain a mixture of episodic and semantic information both for the near and far future, the proportion of episodic and semantic components likely differs according to temporal distance. Indeed, there is evidence that people represent far future events more in terms of abstract goal-related knowledge (e.g., the “why” aspects of an action) and near future events more in terms of concrete details about the means for achieving their goals (e.g., the “how” details of the action) (Trope and Liberman, 2003). The present result that the feeling of experiencing the events was higher for near than for far future events might reflect these differences in levels of concreteness (see also D’Argembeau and Van der Linden, 2004). Our fMRI data regarding the effect of temporal distance also fit well with these ideas. Activity in the lateral temporal cortex and left inferior frontal gyrus have been observed during semantic processing (Poldrack et al., 1999; Vandenberghe et al., 1996). In the context of autobiographical memory, it is thought to reflect the retrieval of general autobiographical knowledge (conceptual knowledge about life periods and goals) that contextualizes event-specific knowledge (Conway, 2005; Svoboda et al., 2006). We speculate that when envisioning future events these regions support the activation of semantic information concerning anticipated future life periods and goals. We further suggest that the ventral part of anterior vmPFC (BA 11) might sustain the retrieval and monitoring of such goal-related knowledge and assign emotional value to mental representations of future events that pertain to these goals, thus helping make decisions that are advantageous in the long-term (Bechara and Damasio, 2005). Another (not necessarily

incompatible) possibility would be that activation of this region reflects the processing of more uncertain future events. Although there are some constraints in the process of imagining far future events (e.g., envisioning events that are plausible with regard to one's goals and resources), the far future is much more open and uncertain than the near future, for which some events have been planned in details and are anticipated with high degrees of certainty. It has been suggested that the ventral part of anterior vmPFC participates in the processing of situations that are less predictable and that involve a degree of uncertainty with respect to outcomes (Bechara and Damasio, 2005; Elliott et al., 2000). Actually, future events' dimensions such as temporal distance, abstractness, and predictability are intimately related, so it is difficult to determine which factor(s) was of primary importance in the present results. Future studies should thus be conducted to disentangle the specific influences of these dimensions.

For the near versus far future, we found increased activations in the left caudate nucleus, especially for positive events. As already noted, the near future is typically represented more in terms of concrete details for achieving goals, such as the "how" details of an action (Trope and Liberman, 2003). In previous studies, the caudate has been associated with planning and the imagination of actions (Gerardin et al., 2000; Jeannerod, 2001). Its role in episodic future thinking might thus consist of supporting the mental simulation of actions one intends to execute in near future events. The caudate has also been associated with reward processing, and more specifically the integration of information about anticipated reward with processes that mediate the behavior leading to reward acquisition (Knutson and Cooper, 2005; Schultz, 2000). Our finding that activation of the caudate was especially related to the imagination of near positive events fit well with these ideas. Perhaps one key aspect of envisioning the near future is to mentally simulate a series of action plans to maximize the probability of attaining forthcoming rewarding situations.

It remains to be explained why only part of the posterior neural system expected to be associated with processing near future events was activated in this study, and in particular why we did not find activation of the posterior vmPFC. One possibility is that there is no strong dissociation between different parts of the vmPFC in relation to envisioning near and far future events, but that some areas are recruited to a greater extent when envisioning the far future. As can be seen from Figure 1, the vmPFC regions engaged for envisioning the near and far future are largely overlapping; yet direct comparison of far and near future demonstrates that the ventral part of anterior vmPFC is recruited to a greater extent for the far future (Figure 2(a)). The distinction between anterior and posterior parts of the vmPFC might thus be more a matter of degree (i.e., the further we go in the future, the more we engage the more anterior vmPFC) than a true dissociation.

Finally, we found that some brain regions were more activated for positive than for negative future events. These results are consistent with a recent study which also showed increased activity in several brain regions (including the vmPFC) for the imagination of positive versus negative future events (Sharot et al., in press). It should be noted, however, that in this latter study positive future events were imagined to be closer in time than negative future events, so it is difficult to disentangle the effects of valence from the effects of temporal distance. In the current study, activation of the dorsal part of anterior vmPFC (BA 10) was specifically associated with the valence of future events. As mentioned above, this part of the vmPFC has been related to self-referential processing (D'Argembeau et al., 2007; Johnson et al., 2002; Kelley et al., 2002; Northoff et al., 2006). There is abundant evidence that most people hold positive views of themselves and their future and are more willing to consider information that bolsters this conception than information that contradicts it (Leary, 2007; Taylor and Brown, 1988). We speculate that activation of the dorsal part of anterior vmPFC (BA 10) might thus reveal a stronger personal involvement when envisioning positive

rather than negative future events. Another possibility would be that activity in this region reflects increased emotional processing (e.g., emotion appraisal, experience, and/or regulation; Phan et al., 2004) for positive events. The other brain regions that were more activated for positive than for negative events (i.e., left dorsolateral PFC, posterior cingulate/retrosplenial cortex, the lateral temporal cortex, left hippocampus, temporoparietal junction, anterior cingulate, and lingual gyrus) have been frequently observed in studies of autobiographical memory (Svoboda et al., 2006) and might reflect increased retrieval and integration of semantic and visuospatial details for positive events. Our finding that ratings for feeling of experiencing were higher for positive than for negative events is consistent with this interpretation (see also D'Argembeau and Van der Linden, 2004).

In conclusion, the present study demonstrates that the neural substrates of mental simulations of future emotional events are modulated by the temporal distance of imagined episodes. Specifically, the ventral part of anterior vmPFC (BA 11) was more active for envisioning emotional situations in the far future, whereas more posterior regions, and more specifically the caudate nucleus was more engaged for envisioning emotional situations in the near future. We argued that the ventral part of anterior vmPFC might support the retrieval and monitoring of long-term goal-related knowledge and assign emotional value to mental images of events pertaining to these goals. On the other hand, striatal regions such as the caudate nucleus might support more concrete simulations of action plans to achieve rewarding situations in the near future.

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Table 1. Ratings obtained during the pre-scan interview and fMRI session

	Near future		Far future		Routine
	Positive	Negative	Positive	Negative	
<i>Pre-scan interview</i>					
Vividness	5.45 ^a	5.73 ^a	5.33 ^a	5.33 ^a	6.80 ^b
	(0.93)	(0.62)	(1.07)	(0.75)	(0.24)
Temporal distance	2.80 ^a	2.67 ^a	5.92 ^b	5.58 ^b	-
	(0.67)	(0.57)	(0.73)	(0.66)	
Valence	2.37 ^a	-2.33 ^b	2.72 ^c	-2.61 ^d	0.23 ^e
	(0.35)	(0.41)	(0.23)	(0.28)	(0.40)
<i>fMRI session</i>					
Feeling of experiencing	3.39 ^{a,b}	3.08 ^{c,d}	3.25 ^{a,c}	2.88 ^d	3.48 ^b
	(0.54)	(0.50)	(0.54)	(0.59)	(0.71)
Time to identify events	1938 ^a	2046 ^a	2003 ^a	1936 ^a	1688 ^b
(in ms)	(1147)	(1193)	(1215)	(1187)	(1160)

Standard deviations are shown in parentheses. Superscript letters indicate significant differences between conditions: means within a row that do not share a superscript were significantly different from each others ($p < .05$).

Table 2. MNI coordinates and Z values for brain regions with increased activity for near future events and far future events relative to routine activities

	MNI coordinates			Z	Voxels
	x	y	z		
<i>Near future > Routine</i>					
Ventromedial PFC (BA 11)	-3	42	-21	4.43 ^a	138
Ventromedial PFC (BA 10)	-3	57	-3	3.93 ^a	
Dorsomedial PFC (BA 9/10)	0	51	24	3.94 ^b	48
L Posterior cingulate/retrosplenial cortex (BA 30/31)	-9	-57	27	5.25 ^b	166
R inferior temporal gyrus (BA 20)	51	12	-39	4.23 ^b	26
L temporoparietal junction (BA 39)	-48	-60	27	3.21 ^b	22
<i>Far future > Routine</i>					
Ventromedial PFC (BA 11)	-3	42	-21	4.69 ^a	325
Ventromedial PFC (BA 10)	0	57	-3	3.98 ^a	
Dorsomedial PFC (BA 9/10)	-3	51	21	3.88 ^b	
Posterior cingulate/retrosplenial cortex (BA 30/31)	-6	-57	27	4.88 ^b	118
L inferior temporal gyrus (BA 20)	-60	-9	-24	4.53 ^b	45
R inferior temporal gyrus (BA 20)	48	-3	-39	4.39 ^b	65
L temporoparietal junction (BA 39)	-48	-63	24	4.44 ^b	88
R temporoparietal junction (BA 39)	48	-60	24	3.61 ^b	30
<i>Conjunction analysis</i>					
Ventromedial PFC (BA 11)	0	45	-21	4.54 ^a	287
Ventromedial PFC (BA 10)	0	57	-6	4.77 ^a	
Dorsomedial PFC (BA 9/10)	-3	51	21	4.69 ^b	
Posterior cingulate/retrosplenial cortex (BA 30/31)	-6	-57	27	6.00 ^b	216
R inferior temporal gyrus (BA 20)	48	-3	-39	4.19 ^b	17
L temporoparietal junction (BA 39)	-48	-63	27	3.66 ^b	61

L = left hemisphere; R = right hemisphere; L and R are not designated for maxima within 6 mm of midline. BA = Brodmann's area. PFC = prefrontal cortex. Ventromedial PFC refers to z coordinate ≤ 0 mm.

^a significant at $p < .05$ corrected for multiple comparisons at the voxel level over small volumes of interest (see Methods section for details)

^b significant at $p < .001$ (uncorrected) with an extent threshold of 10 voxels

Table 3. MNI coordinates and Z values for brain regions associated with the effect of temporal distance

Brain region	MNI coordinates			Z	Voxels
	x	y	z		
<i>Far future > Near future</i>					
Ventromedial PFC (BA 11)	-3	51	-18	4.15 ^a	31
L middle temporal gyrus (BA 21)	-51	-9	-15	4.24 ^b	13
R inferior temporal gyrus (BA 20)	54	-12	-33	3.90 ^b	29
L inferior temporal gyrus (BA 20)	-60	-15	-30	3.54 ^b	20
L inferior frontal gyrus (BA 47)	-42	36	-18	3.75 ^b	16
<i>Near future > Far future</i>					
L caudate nucleus	-12	21	-3	4.20 ^a	20

L = left hemisphere; R = right hemisphere; L and R are not designated for maxima within 6 mm of midline. BA = Brodmann's area. PFC = prefrontal cortex. Ventromedial PFC refers to z coordinate ≤ 0 mm.

^a significant at $p < .05$ corrected for multiple comparisons at the voxel level over small volumes of interest (see Methods section for details)

^b significant at $p < .001$ (uncorrected) with an extent threshold of 10 voxels

Table 4. MNI coordinates and Z values for brain regions associated with the effect of valence

Brain region	MNI coordinates			Z	Voxels
	x	y	z		
<i>Positive > Negative</i>					
Ventromedial PFC (BA 10)	0	57	-3	4.03 ^a	109
L caudate nucleus	-12	15	3	3.98 ^a	4
L middle/superior frontal gyrus (BA 8/9)	-24	30	54	5.11 ^b	142
Posterior cingulate/retrosplenial cortex (BA 30/31)	-6	-63	18	4.77 ^b	339
R inferior temporal gyrus (BA 20)	51	-18	-24	3.97 ^b	41
L middle temporal gyrus (BA 21)	-57	-33	3	3.65 ^b	14
R inferior temporal gyrus (BA 20/37)	66	-48	-12	3.63 ^b	12
L inferior temporal gyrus (BA 37)	-57	-54	-18	3.49 ^b	14
R temporoparietal junction (BA 39)	51	-72	21	4.19 ^b	27
L temporoparietal junction (BA 39)	-42	-75	24	3.92 ^b	34
L hippocampus	-18	-15	-15	3.67 ^b	23
R parahippocampal gyrus (BA 35)	24	-27	-15	3.35 ^b	17
Anterior cingulate (BA 24)	-5	30	18	3.43 ^b	31
Lingual gyrus (BA 18)	-3	-78	-3	3.51 ^b	15

L = left hemisphere; R = right hemisphere; L and R are not designated for maxima within 6 mm of midline. BA = Brodmann's area. PFC = prefrontal cortex. Ventromedial PFC refers to z coordinate ≤ 0 mm.

^a significant at $p < .05$ corrected for multiple comparisons at the voxel level over small volumes of interest (see Methods section for details)

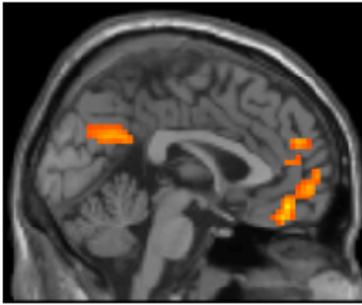
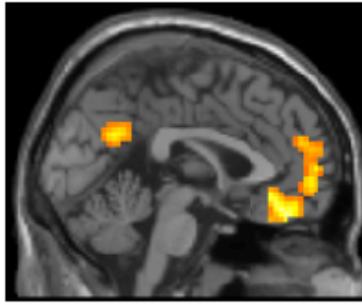
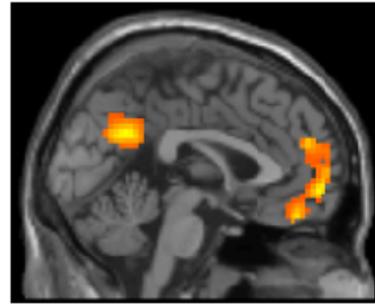
^b significant at $p < .001$ (uncorrected) with an extent threshold of 10 voxels

Figure legends

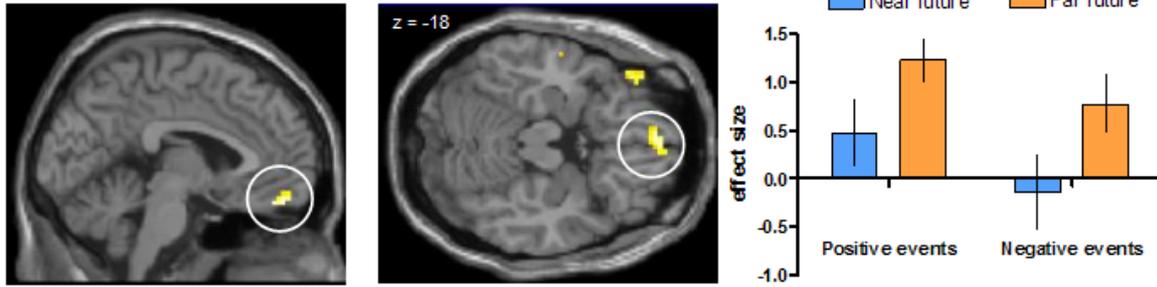
Figure 1. Activations in medial prefrontal and medial posterior regions associated with (a) imagining near future events relative to routine activities, (b) imagining far future events relative to routine activities, and (c) the conjunction of near and far future events. Displayed at $p < .001$ (uncorrected) with an extent threshold of 10 voxels.

Figure 2. Brain regions associated with the main effect of temporal distance: (a) activation in the ventromedial PFC (BA 11; peak activation at $x = -3, y = 51, z = -18$) when imagining the far future relative to the near future; (b) activation in the left caudate nucleus (peak activation at $x = -12, y = 21, z = -3$) when imagining the near future relative to the far future. Displayed at $p < .001$ (uncorrected) with an extent threshold of 10 voxels. Effect sizes correspond to average beta weight values from a 6mm sphere constructed around the local maximum for the group effect. Error bars represent the standard error of the mean.

Figure 3. Activation in the ventromedial PFC (BA 10; peak activation at $x = 0, y = 57, z = -3$) when imagining positive relative to negative future events. Displayed at $p < .001$ (uncorrected) with an extent threshold of 10 voxels. Effect sizes correspond to average beta weight values from a 6mm sphere constructed around the local maximum for the group effect. Error bars represent the standard error of the mean.

a Near future > Control**b** Far future > Control**c** Conjunction

a Far future > near future



b Near future > far future



