The Neural Basis of Personal Goal Processing When Envisioning Future Events

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Abstract

■ Episodic future thinking allows humans to mentally simulate virtually infinite future possibilities, yet this device is fundamentally goal-directed and should not be equated with fantasizing or wishful thinking. The purpose of this fMRI study was to investigate the neural basis of such goal-directed processing during future-event simulation. Participants were scanned while they imagined future events that were related to their personal goals (personal future events) and future events that were plausible but unrelated to their personal goals (nonpersonal future events). Results showed that imaging personal future events elicited stronger activation in ventral medial prefrontal cortex (MPFC) and posterior cingulate cortex (PCC) compared to imaging nonpersonal future events. Moreover, these brain activations overlapped with activations elicited by a second task that assessed semantic self-knowledge (i.e., making judgments on one's own personality traits), suggesting that ventral MPFC and PCC mediate self-referential processing across different functional domains. It is suggested that these brain regions may support a collection of processes that evaluate, code, and contextualize the relevance of mental representations with regard to personal goals. The implications of these findings for the understanding of the function instantiated by the default network of the brain are also discussed. ■

INTRODUCTION

Our capacity to "pre-experience" the future by simulating it in our minds has attracted increased attention in various areas of psychology and neuroscience during the past few years (for reviews, see Szpunar, in press; Schacter, Addis, & Buckner, 2008; Gilbert & Wilson, 2007; Suddendorf & Corballis, 2007; Tulving, 2005; Atance & O'Neill, 2001; Taylor, Pham, Rivkin, & Armor, 1998). This growing interest stems in large part from the recognition that the ability to envisage and mentally "try out" multiple versions of the future has a strong adaptive value, allowing, in particular, to consider potential consequences prior to acting, hence, to override immediate impulses in favor of longer-term goals (Boyer, 2008; Schacter et al., 2008; D'Argembeau & Van der Linden, 2007; Suddendorf & Corballis, 2007; Bechara, 2005; Tulving, 2005). Recent functional neuroimaging studies have revealed that this capacity to envision or simulate possible future scenarios, here referred to as "episodic future thinking" (Atance & O'Neill, 2001), relies on a specific set of brain regions that includes medial prefrontal cortex (MPFC), medial and lateral temporal regions, posterior cingulate (PCC)/retrosplenial cortex, and inferior parietal lobe (Botzung, Denkova, & Manning, 2008; D'Argembeau, Xue, Lu, Van der Linden, & Bechara, 2008; Addis, Wong, & Schacter, 2007; Hassabis, Kumaran, & Maguire, 2007; Sharot, Riccardi, Raio, & Phelps, 2007; Szpunar, Watson, & McDermott, 2007; Okuda et al., 2003). Remarkably similar brain regions have also been associated with other functions or states, including autobiographical memory, navigation, theory of mind, and the "default mode" (for a recent meta-analysis, see Spreng, Mar, & Kim, 2009), suggesting that this core network of brain regions supports a number of processes that are common to different functional domains (Buckner & Carroll, 2007). The exact nature of these processes, however, is still debated (cf. Schacter et al., 2008; Buckner & Carroll, 2007; Hassabis & Maguire, 2007) and requires further empirical investigation.

Episodic future thinking involves multiple component processes (Suddendorf & Corballis, 2007), including the retrieval and integration of relevant information from memory (Schacter et al., 2008; Hassabis & Maguire, 2007), the processing of subjective time (Tulving, 2002, 2005; Klein, Loftus, & Kihlstrom, 2002), and self-referential processing (Conway, 2005; Tulving, 2002, 2005). Recent fMRI studies suggest that specific processes, such as the retrieval of episodic details (Addis & Schacter, 2008), contextual processing (Szpunar, Chan, & McDermott, 2009), and the processing of temporal distance (Addis & Schacter, 2008; D'Argembeau, Xue, et al., 2008), depend on distinct brain areas within the core network described above. The neural basis of other component processes that are integral to episodic future thinking remains poorly understood,

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however. In particular, self-referential and goal processing have received relatively little empirical attention, yet episodic future thinking is fundamentally a goal-directed process and is not to be confounded with fantasizing or wishful thinking (Karniol & Ross, 1996; Johnson & Sherman, 1990). From this perspective, episodic future thinking involves more than merely retrieving and integrating episodic details (e.g., details about objects, people, places, and so on) to construct mental images of coherent scenes. Another important aspect of episodic future thinking consists of envisioning future events in relation to personal goals and the self-schema (Conway, 2005; Karniol & Ross, 1996; Johnson & Sherman, 1990; Markus & Nurius, 1986), for example, picturing future states of the self that one aspires to attain, conceiving ways to achieve those states, and anticipating potential obstacles to one's plans. The purpose of the current fMRI study was to investigate the neural basis of such self-referential processes during future-event simulation.

It should be noted beforehand that self-referential processing is not unitary, but comprises multiple aspects or levels (e.g., Morin, 2006; Klein, Rozendal, & Cosmides, 2002; Gallagher, 2000; Damasio, 1999). With regard to episodic memory and future thinking, at least two dimensions can be distinguished: representing oneself as an agent and subject of experience (i.e., remembering or imagining a personal experience, rather than the experience of someone else), and processing the represented events in relation to personal goals and the self-schema (e.g., attaching personal significance to represented events). The first aspect has been addressed in several functional neuroimaging studies that manipulated the subject of the represented events, either oneself versus someone else (Summerfield, Hassabis, & Maguire, 2009; Szpunar et al., 2007) or oneself versus states of the world (Abraham, Schubotz, & von Cramon, 2008). On the other hand, the brain regions that process events in relation to personal goals and the self-schema remain to be investigated in detail. There is evidence that thinking about personal agendas (i.e., hopes and aspirations or duties and obligations) elicits greater activity in MPFC and medial posterior regions (PCC/precuneus) compared to thinking about non-self-relevant topics (Johnson et al., 2006). It is unclear, however, whether the tasks used in that study involved episodic future thinking (i.e., future-event simulation) or merely semantic self-knowledge (i.e., abstract knowledge about personal agendas). In a recent fMRI study, we found that ventral MPFC was more strongly activated when envisioning personally significant events in the more distant future (i.e., years vs. weeks from now) (D'Argembeau, Xue, et al., 2008). Considering that higher-level goals are used to represent more distant future events (Trope & Liberman, 2003), we suggested that ventral MPFC might be involved in personal goal processing and, more specifically, in assigning value to mental representations that are relevant to personal goals. This proposed role of ventral MPFC is still very tentative, however, and requires further empirical investigation. The main purpose of the current study was to test this hypothesis more directly by explicitly manipulating the relevance of future events with regard to personal goals.

Specifically, during fMRI scanning, we asked participants to imagine future events that are relevant to their personal goals (personal future events; e.g., going to ski in two weeks, moving in a new apartment in two months, getting married next summer) and future events that are plausible and can be vividly imagined but are unrelated to their personal goals (nonpersonal future events; e.g., going to the zoo in two weeks, buying a clock at the flea market in two months, taking a pottery lesson next summer), as determined by individualized prescan interviews. As a control task, participants were asked to imagine routine activities (e.g., taking a shower, washing the dishes, commuting to school), which involved the construction of mental representations of complex scenes but lacked the process of locating the events in subjective time (D'Argembeau, Xue, et al., 2008). The three types of events were selected during a prescan interview and care was taken to match personal and nonpersonal future events for vividness and temporal distance. During the fMRI session, participants were instructed to project themselves in each event and imagine it in as much detail as possible (i.e., imagining the objects and persons involved, the location, the unfolding of the event, and so on) in order to mentally experience the situation. Our main interest was in contrasting the imagination of personal and nonpersonal future events in order to isolate the brain regions that are specifically related to personal goal processing during future-event simulation. In addition, we also isolated the brain regions associated with self-referential processing using a second, independent task (i.e., making judgments about one's own personality traits) that has been extensively used in earlier fMRI studies (D'Argembeau, Feyers, et al., 2008; D'Argembeau et al., 2007; Pfeifer, Lieberman, & Dapretto, 2007; Heatherton et al., 2006; Mitchell, Macrae, & Banaji, 2006; Ochsner et al., 2005; Lieberman, Jarcho, & Satpute, 2004; Schmitz, Kawahara-Baccus, & Johnson, 2004; Fossati et al., 2003; Kelley et al., 2002) and that depends on semantic more than episodic forms of self-knowledge (Klein, Robertson, Gangi, & Loftus, 2008; Klein, Rozendal, et al., 2002). By looking at the overlap between brain activation related to this task and brain activation associated with personal goal processing in episodic future thinking, we sought to identify the cerebral structures that underlie self-referential processing across different functional domains.

METHODS

Participants

Twenty right-handed adults (10 women) aged between 18 and 28 years (mean age = 23 years) participated in the experiment. They all gave their written informed consent to take part in the study, which was approved by the Ethics Committee of the Medical School of the University of Liège. None of the participants had any history of neurological or psychiatric disorder.

Tasks Description and Procedures

Prescan Interview

The day before the fMRI session, participants took part in a detailed interview the purpose of which was to generate the three types of events that would be mentally simulated during the fMRI session. Participants were first asked to fill out an adaptation of the Personal Project Analysis Inventory (Little, 1983). In total, participants were asked to list 10 personal projects. Personal projects were defined as things that are personally important, for which we make plans and that we strive to achieve. It was further specified that personal projects can refer to any future period (i.e., close or distant in time) and can relate to various life domains (e.g., school or work, family, intimate relationship, material goods, leisure activities). Then, for each personal project, participants had to imagine a specific event (i.e., something specifically located in place and time and lasting less than a day) in relation to that project. Examples were provided to illustrate what a specific event might be (e.g., for the personal project "becoming a doctor," a specific event might be the imagination of one's graduation ceremony; when representing a specific event, the individual is able to imagine details about the environment, persons and objects that are present, the unfolding of the event, and so forth; cf. D'Argembeau & Van der Linden, 2004). For each specific event, participants also provided an approximate time period when the event would occur. A short sentence summarizing the essence of the event was created for use in the fMRI session (e.g., graduation ceremony in two years).

Participants were then asked to select 10 "nonpersonal" future events. Nonpersonal future events were defined as events that can be vividly imagined and that could possibly happen in the future, although they are not part of personal projects and are not particularly self-relevant. A list of potential events was provided (e.g., taking one's first golf lesson, handing out leaflets for an ecological organization, going to see a car race). For each event on the list, the interviewer asked a series of questions to investigate whether participants were able to imagine the event vividly (i.e., whether they were able to imagine details about the environment, the persons and objects that are present, the unfolding of the event, and so forth) and to verify that the event was not related to one of their personal projects. Only events that fulfilled these criteria were selected for the fMRI session. A future time period was then assigned to each selected event (e.g., going to see a car race in two weeks) so as to match personal and nonpersonal future events with regard to temporal distance.

Finally, participants were asked to select 10 routine activities, that is, things they do on a regular basis and for which they can create generic mental images (i.e., imagining the activity as it typically unfolds, without the need to remember a particular occasion in time). A list of routine activities was provided (e.g., taking a shower, washing the dishes, commuting to school) and participants were asked to select activities that they can vividly imagine (i.e., imagining details about the environment, the persons and objects that are present, the unfolding of the event, and so forth) without the need to remember a particular occasion in time.

fMRI Session

Episodic future thinking task. During the fMRI session, participants were asked to imagine the future events and routine activities that had been selected the day before. Each event was cued by a slide that contained one line with a written description of the type of event (i.e., personal future, plausible future, or routine activity) and another line with the cue created during the prescan interview (e.g., "graduation ceremony in two years," "going to see a car race in two weeks," "taking a shower"). For future events, participants were instructed to mentally 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 so forth. For routine activities, they were also instructed to mentally project themselves in each situation 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, however, that they should consider each routine activity without reference to a particular event located in time (i.e., imagining the activity as it typically unfolds, instead of remembering a particular occasion when they did this activity). Thus, imagining routine activities involved the construction of mental representations of complex scenes with a spatial context but lacked the process of locating the events in subjective time.

Each trial started with the presentation of the cue slide. Participants were asked to read the cue in order to identify the corresponding event, then to close their eyes and to press a button to indicate that they began to imagine the event. This stage was self-paced and could take up to 5 sec (a beep was presented to confirm button press). Participants then imagined the event with eyes closed for 15 sec (imagination phase). After 15 sec, participants heard a beep indicating that the imagination phase is over and that they need to open their eyes; a fixation cross was presented on the screen before the next trial began (jittered between 4 and 12 sec; random Gaussian distribution centered on a mean duration of 8 sec). The cues were presented in pseudorandom order, such that a particular condition could not be repeated immediately and could not be separated by more than four trials of a different condition. All cues were presented once and their presentation was then repeated (in the same order, such that the two occurrences of a given cue were 30 trials apart), leading to 20 imagination trials per condition. A potential problem with presenting the same cues twice is that participants might be less engaged in the imagination process for the second presentation of the cue. In order to minimize that possibility, it was specified that participants were not required to imagine exactly the same content the second time that they were presented with a particular cue (e.g., they could think of additional details), the important point being that, on each trial, they try to project themselves into the event in as much detail as possible in order to mentally experience the situation. Immediately after the scanning session, participants were presented with all cues again and were asked to rate the extent to which they were able to imagine each event vividly and in a detailed way while they were in the scanner (from 1 = vague with no details, to 7 = very vivid and highly detailed). For future events, participants were also asked to rate the personal importance of the events (from 1 = not at all important, to 7 = very important).

Semantic self-referential task. Following the episodic future thinking task, participants completed a task that has been previously used to investigate self-referential processing in the semantic domain (D'Argembeau, Feyers, et al., 2008; D'Argembeau et al., 2007; Heatherton et al., 2006; Moran, Macrae, Heatherton, Wyland, & Kelley, 2006; Schmitz et al., 2004; Fossati et al., 2003; Kelley et al., 2002). Briefly, the task consisted of making different types of judgments on adjectives describing personality traits (e.g., modest, shy). One condition required participants to decide whether or not the adjectives described their own personality characteristics (self condition), whereas in another condition they were asked to decide whether or not the adjectives designated a positive trait (control condition). Two other conditions were also included (judging one's own past and future personality characteristics) but they were not of interest for the purpose of this study so we do not discuss them further. The different types of judgments were presented in 10 blocks of four trials. Before the start of each block, an instruction cue appeared on the screen (for a variable duration: random normal distribution with a mean duration of 3000 msec and standard deviation of 500 msec) to inform participants about the type of judgment they had to make for the adjectives presented subsequently. The four trials were then presented sequentially. Each trial consisted of the presentation of an adjective for 3500 msec, during which participants made a yes/no decision by pressing one of two buttons, followed by a variable interstimulus interval (random normal distribution with a mean duration of 1250 msec and standard deviation of 350 msec). Between each block, a fixation cross was presented for a variable duration comprised between 5000 and 6000 msec. Blocks were presented in pseudorandom order, such that all conditions were presented before their presentation was repeated and with the restriction that two blocks of the same condition could not be repeated immediately and could not be separated by more than six blocks of a different condition.

MRI Acquisition

Data were acquired on a 3Tesla scanner (Siemens, Allegra, Erlangen, Germany) using a T2*-sensitive gradient-echo EPI sequence (TR = 2130 msec, TE = 40 msec, FA = 90°, matrix size = $64 \times 64 \times 32$ voxels, voxel size = $3.4 \times 3.4 \times 3.4$ mm^3). Thirty-two 3-mm-thick transverse slices (FOV = 22×22 cm^2) were acquired, with a distance factor of 30%, covering the whole brain. Between 714 and 758 functional volumes were acquired for the episodic future thinking task and 516 functional volumes were acquired for the semantic self-referential task. The first three volumes were discarded to account for T1 saturation. A structural MR scan was obtained at the end of the session (T1-weighted 3-D MP-RAGE sequence, TR = 1960 msec, TE = 4.4 msec, FOV = 23×23 cm^2, matrix size = $256 \times 256 \times 176$, voxel size = $0.9 \times 0.9 \times 0.9$ mm^3). Head movement was minimized by restraining the subject's head using a vacuum cushion. Stimuli were displayed on a screen positioned at the rear of the scanner, which the subject could comfortably see through a mirror mounted on the standard head coil.

fMRI Data Analyses

fMRI data were preprocessed and analyzed using SPM5 (Wellcome Department of Imaging Neuroscience, www.fil.ion.ucl.ac.uk/spm) implemented in MATLAB (Mathworks, Sherborn, MA). Functional scans were realigned using iterative rigid-body transformations that minimize the residual sum of squares between the first and subsequent images. They were normalized to the MNI EPI template (voxel size = $2 \times 2 \times 2$ mm^3) and spatially smoothed with a Gaussian kernel with full width at half maximum (FWHM) of 8 mm.

Episodic Future Thinking Task

For each participant, BOLD responses were modeled at each voxel using a general linear model. The cue presentation, first beep, imagination phase, and second beep were modeled separately for the three conditions (personal future, nonpersonal future, routine activities). The cue presentation and imagination phases were modeled as epoch-related responses and the two beeps were modeled as event-related responses. The design matrix also included the realignment parameters to account for any residual movement-related effect. The canonical HRF was used. A high-pass filter was implemented using a cutoff period of 128 sec in order to remove the low-frequency drifts from the time series. Serial autocorrelations were estimated with a restricted maximum likelihood algorithm with an autoregressive model of order 1 (+ white noise). For each individual participant, we first contrasted the imagination phase of personal future events with the imagination phase of routine activities (personal future–routine) and the imagination phase of nonpersonal future events with the imagination phase of routine activities (nonpersonal future–routine). Then, the two types of future events were directly contrasted (personal future–nonpersonal future). The corresponding contrast images were smoothed (6-mm FWHM Gaussian kernel) in order to reduce remaining noise due to intersubject differences in anatomical variability in the individual contrast images. They were then entered in a second-level random effect analysis using standard t-test analyses.

Semantic Self-referential Task

For each participant, BOLD responses were modeled at each voxel using a general linear model. All four conditions were modeled as epoch-related responses. For each condition, each epoch ranged from the onset of the first adjective on the screen until the last adjective disappeared from the screen. Boxcar functions representative of these epoch regressors were convolved with the canonical hemodynamic response. The design matrix also included the realignment parameters to account for any residual movement-related effect. A high-pass filter was implemented using a cutoff period of 128 sec in order to remove the low-frequency drifts from the time series. Serial autocorrelations were estimated with a restricted maximum likelihood algorithm with an autoregressive model of order 1 (+ white noise). In this study, we were interested in contrasting self-referential judgments with valence judgments (self–control) in order to isolate the brain regions that underlie self-referential processing in the semantic domain. The corresponding contrast images were smoothed (6-mm FWHM Gaussian kernel) in order to reduce remaining noise due to intersubject differences in anatomical variability in the individual contrast images. They were then entered in a second-level random effect analysis using standard t-test analyses.

For a priori regions of interest, statistical inferences were corrected for multiple comparisons using Gaussian random field theory at the voxel level in a small spherical volume (radius 10 mm) around coordinates selected from the literature on self-referential processing and episodic future thinking. These a priori regions of interest concerned areas in ventral and dorsal MPFC (−6, 46, −10; −6, 54, −2; −2, 56, 26; D'Argembeau, Feyers, et al., 2008; D'Argembeau et al., 2007) (in this study, we refer to ventral MPFC for z coordinate ≤ 10 mm and to dorsal MPFC for z coordinate > 10 mm), PCC (−2, −62, 32; Johnson et al., 2002), inferior parietal lobe/temporo-parietal junction (−48, −62, 26; 48, −60, 24; D'Argembeau, Xue, et al., 2008), and lateral temporal lobe (−60, −8, −24; D'Argembeau, Xue, et al., 2008). Other regions were considered if they survived a threshold of $p < .05$, corrected for multiple comparisons over the entire volume using the family-wise error correction. For completeness, the tables also list regions that survived a threshold of $p < .001$, uncorrected for multiple comparisons with a minimum cluster size of 20 voxels, but these regions are not discussed further.

RESULTS

Postscan Reports and Ratings

Interviews conducted immediately after the fMRI session indicated that participants were able to mentally project themselves into the three types of events each time the relevant cues were presented (i.e., they did not simply remember imagining the events during the prescan interview). The postscan interviews also indicated that participants were able to mentally simulate routine activities in a temporally decontextualized way (i.e., without remembering specific instances when they did the activities). Ratings of vividness/amount of details confirmed that participants were able to imagine the three types of events in a detailed way ($M = 5.14$, $SD = 0.57$, for personal future events; $M = 4.93$, $SD = 0.57$, for nonpersonal future events; and $M = 5.40$, $SD = 0.70$, for routine activities). A one-way ANOVA revealed that the ratings differed across the three types of events [$F(2, 38) = 4.53, p = .02$], and post hoc comparisons (Tukey's HSD tests) showed that vividness ratings were significantly higher for routine activities than for nonpersonal future events ($p = .02$). The difference between routine activities and personal future events was in the same direction but was not statistically significant ($p = .23$). Importantly, personal and nonpersonal future events did not differ from each other ($p = .37$), suggesting that it is unlikely that the differences in brain activation discussed below can be accounted for by vividness/amount of details. Ratings of personal importance confirmed that personal future events were perceived as more important than nonpersonal future events [$M = 5.43$, $SD = 0.69$ vs. $M = 1.91$, $SD = 0.60$; $t(19) = 18.66$, $p < .001$].

fMRI Data

Episodic Future Thinking

The imagination of personal future events was associated with activations in a large portion of MPFC [encompassing Brodmann's areas (BA) 9, 10, and 11], in PCC, in inferior parietal lobe, and in lateral temporal lobe, relative to the imagination of routine activities (Table 1, Figure 1A). The imagination of nonpersonal future events was also associated with activation in MPFC (relative to the imagination of routine activities) but the focus of activation was less extended than for personal future events (Table 1, Figure 1B). As can be seen from Figure 1, the contrast between nonpersonal future events and routine activities was associated with activation restricted to the most ventral part of MPFC (BA 11), whereas the contrast between

Table 1. Brain Regions Associated with the Imagination of Personal and Nonpersonal Future Events Compared to Routine Activities

	MNI Coordinates			
	x	*y*	*z*	*Z-score*
Personal Future Events > Routine Activities				
Ventral MPFC (BA 10/11)	−4	48	−14	4.78*
Ventral MPFC (BA 10)	−6	60	6	4.38*
Dorsal MPFC (BA 9/10)	−6	60	18	4.09*
Posterior cingulate cortex	−2	−58	26	4.28*
Left inferior parietal lobe	−48	−68	28	4.97*
Right inferior parietal lobe	56	−64	24	3.77*
Left inferior/middle temporal gyrus	−60	−8	−28	3.70*
Right middle temporal gyrus	58	2	−26	3.31**
Right cerebellum	32	−82	−36	3.38**
Nonpersonal Future Events > Routine Activities				
Ventral MPFC (BA 11)	−2	50	−18	3.21*
Dorsal MPFC (BA 9)	8	56	26	3.72*
Left temporo-parietal junction	−48	−56	20	3.43*
Right temporo-parietal junction	48	−54	20	3.55*
Left inferior temporal gyrus	−60	−16	−30	4.95*
Left inferior temporal gyrus/fusiform gyrus	−32	−6	−40	3.42**
Right temporal pole	48	18	−32	3.77**
Left hippocampus	−22	−8	−22	4.02**

MPFC = medial prefrontal cortex. Ventral MPFC refers to z coordinate ≤ 10 mm and dorsal MPFC to z coordinate > 10 mm.

*Significant at $p < .05$, corrected for multiple comparisons at the voxel level over small volumes of interest (see Methods for details).

**Significant at $p < .001$, uncorrected for multiple comparisons with a minimum cluster size of 20 voxels.

personal future events and routine activities was associated with activation that extended dorsally to BAs 10 and 9. The contrast between nonpersonal future events and routine activities was also associated with foci of activation in dorsal MPFC (BA 9), temporo-parietal junction, and lateral temporal lobe (Table 1, Figure 1B). No activation was detected in PCC, even at a more permissive statistical threshold ($p < .005$, uncorrected for multiple comparisons).

Our main interest in this study was to directly contrast the imagination of personal and nonpersonal future events in order to investigate the neural basis of personal goal processing during future-event simulation. This comparison showed that the imagination of personal future events was associated with increased activation in ventral MPFC (encompassing BAs 10 and 11) and PCC, relative to the imagination of nonpersonal future events (Table 2, Figure 2A). Examination of parameter estimates (Figure 2B) revealed that the three imagination conditions were, in fact, associated with activity decreases in these cortical regions relative to baseline (i.e., passive fixation). Interestingly, however, decreases of activity were less pronounced when imagining personal future events than when imagining nonpersonal future events and routine activities.

Self-referential Processing across Semantic and Episodic Domains

In line with earlier studies (e.g., D'Argembeau, Feyers, et al., 2008; Moran et al., 2006; Schmitz et al., 2004; Fossati et al., 2003; Johnson et al., 2002; Kelley et al., 2002), the semantic self-referential task (i.e., making judgments about one's own personality traits vs. valence judgments) was associated with activation in MPFC (in both ventral and dorsal portions of MPFC) and PCC (Table 3). Foci of activation were also detected in left lateral temporal lobe and left inferior parietal lobe. To allow the visual comparison between activation associated with the semantic self-referential task and activation associated with the imagination of personal versus nonpersonal future events, Figure 3 displays the two contrasts simultaneously. As can be seen, the two contrasts overlapped in ventral MPFC (especially

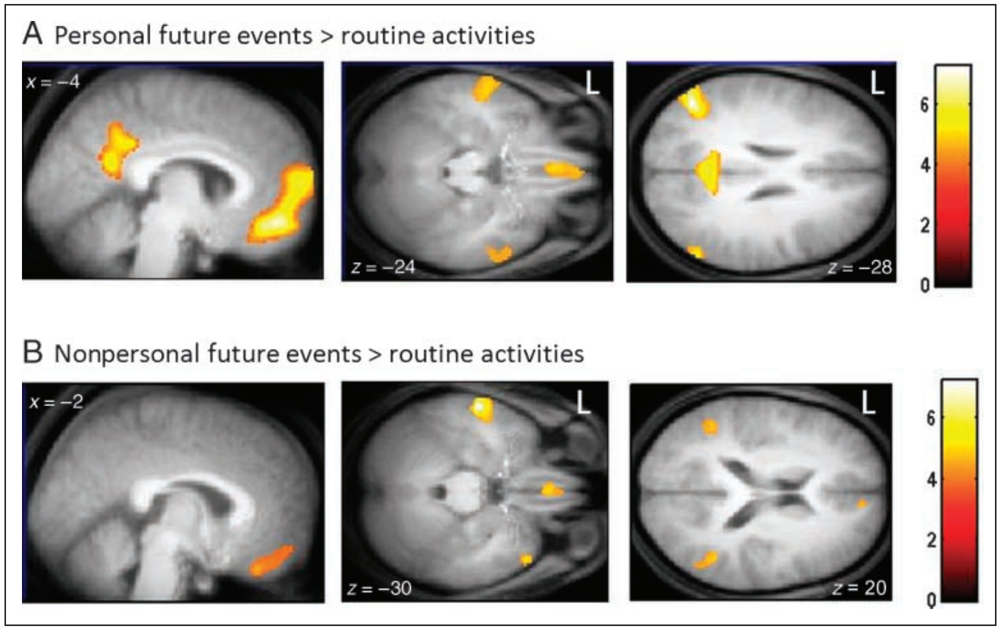

Figure 1. Brain regions associated with the imagination of personal and nonpersonal future events compared to routine activities. (A) The imagination of personal future events versus routine activities was associated with increased activation in a large portion of MPFC, in PCC, in lateral temporal lobe, and in inferior parietal lobe. (B) The imagination of nonpersonal future events versus routine activities was associated with activation in a smaller portion of MPFC. Foci of activation were also detected in lateral temporal lobe and temporo-parietal junction. Displayed at $p < .001$ (uncorrected) on the mean structural MRI of all participants.

in BA 10) and in PCC. The two contrasts did not overlap in any other brain region.

DISCUSSION

In line with earlier studies of episodic future thinking (Szpunar et al., 2007, 2009; Botzung et al., 2008; D'Argembeau, Xue, et al., 2008; Addis et al., 2007; Sharot et al., 2007; Okuda et al., 2003), a network of brain regions that included MPFC, PCC, inferior parietal lobe, and lateral temporal lobe was more activated when participants imagined personal future events (i.e., future events that were related to their personal goals) than when they imagined routine activities. The imagination of nonpersonal future events (i.e.,

Table 2. Brain Regions Associated with the Imagination of Personal versus Nonpersonal Future Events

	MNI Coordinates			
	x	*y*	*z*	*Z-score*
Personal Future > Nonpersonal Future				
Ventral MPFC (BA 10/11)	−6	48	−10	5.33*
Ventral MPFC (BA 10)	−10	60	2	4.39*
Posterior cingulate cortex	4	−56	28	4.53*
Left parieto-occipital area	−50	−72	40	4.44**
Left superior frontal sulcus	−12	32	42	4.23**
Nonpersonal Future > Personal Future				
Left inferior parietal lobe	−64	−34	46	4.62**
Right inferior parietal lobe	64	−34	42	4.02**
Left superior temporal sulcus	−44	−4	−16	4.10**
Left inferior/middle temporal gyrus	−54	−62	2	4.09**
Left inferior temporal gyrus/fusiform gyrus	−36	−8	−38	3.82**
Right fusiform gyrus	34	−64	−14	3.90**

MPFC = medial prefrontal cortex. Ventral MPFC refers to z coordinate ≤ 10 mm.

*Significant at $p < .05$, corrected for multiple comparisons at the voxel level over small volumes of interest (see Methods for details).

**Significant at $p < .001$, uncorrected for multiple comparisons with a minimum cluster size of 20 voxels.

future events that were plausible but unrelated to personal goals) versus routine activities was associated with activation in similar brain regions, except for PCC and the upper part of ventral MPFC (BA 10). Our main interest was then to directly contrast the imagination of personal and nonpersonal future events in order to isolate the brain regions that support personal goal processing during episodic future thought. This comparison revealed that ventral MPFC and PCC showed greater activation when imaging personal future events relative to nonpersonal future events. Importantly, these two types of future events involved self-projection (i.e., representing oneself as the subject of the imagined experiences) and were matched for vividness and temporal distance, suggesting that differences in brain activation cannot be accounted by these factors alone. The current findings thus suggest that ventral MPFC and PCC may play a specific role in personal goal processing during episodic future thinking.

We also sought to investigate whether common brain regions are implicated in self-referential processing across different functional domains. To this end, we isolated the brain regions that were associated with self-referential processing using a second independent task that has been extensively used in earlier fMRI studies (e.g., D'Argembeau, Feyers, et al., 2008; Moran et al., 2006; Schmitz et al., 2004; Fossati et al., 2003; Johnson et al., 2002; Kelley et al., 2002) and that depends on semantic more than episodic self-knowledge (Klein et al., 2008; Klein, Rozendal, et al., 2002). We then looked at the overlap between brain activation related to this task and brain activation associated with self-referential processing in the episodic domain (i.e., imaging personal vs. nonpersonal future events). Brain activations associated with the two tasks overlapped in ventral MPFC (especially in BA 10) and in PCC. There is evidence that semantic and episodic forms of self-knowledge (i.e., abstract knowledge about one's own personal characteristics vs. representations of specific self-relevant experiences) are represented separately (Klein et al., 2008; Klein, Rozendal, et al., 2002), yet it is likely that they engage common self-referential processes (e.g., appraisal of self-relevance). The current data suggest that such common processes are, in part, supported by ventral MPFC and PCC, which is consistent with the view that cortical midline structures support self-referential processing across different functional domains (Northoff et al., 2006). We next discuss in more detail what might be the specific function of ventral MPFC and PCC.

MPFC has been implicated in various tasks, not only tasks requiring explicit self-referential processing but also tasks investigating emotion processing and decision-making (Bechara, Damasio, & Damasio, 2000), reward processing (Knutson & Cooper, 2005; O'Doherty, 2004; Schultz, 2000), and mentalizing about others (Mitchell, 2009; Van Overwalle, 2009; Lieberman, 2007; Amodio & Frith, 2006), to name just a few of them. Although distinct parts of MPFC may support different functions (Amodio & Frith, 2006), it is also likely that common processes are involved in the various tasks that have been associated with activation

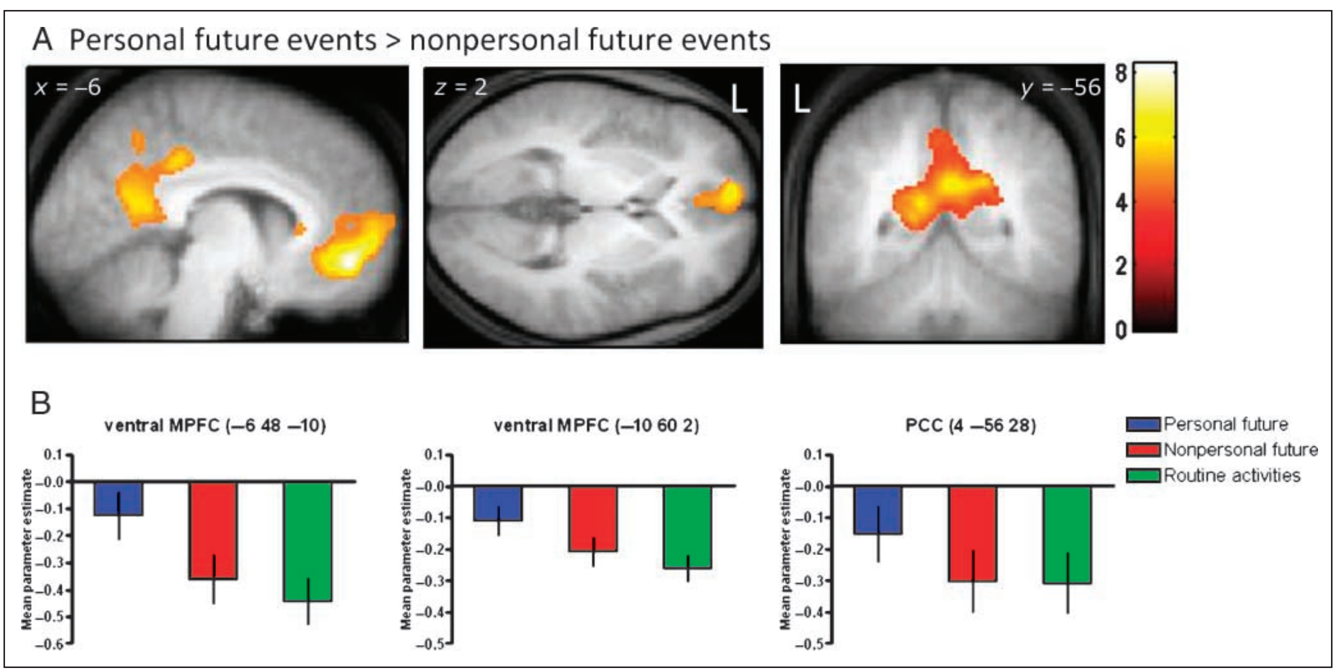

Figure 2. Brain regions associated with the imagination of personal versus nonpersonal future events. (A) The imagination of personal future events was associated with increased activation in ventral MPFC (encompassing BAs 10 and 11) and PCC. Displayed at $p < .001$ (uncorrected) on the mean structural MRI of all participants. (B) Examination of parameter estimates (averaged over all voxels within a 10-mm radius of the peak voxel) revealed that decreases of activity in ventral MPFC and PCC relative to baseline (passive fixation) were less pronounced when imagining personal future events than when imagining nonpersonal future events and routine activities. Error bars represent the standard error of the mean.

Table 3. Brain Regions Associated with Self-referential Judgments on Personality Traits

	MNI Coordinates			
	x	*y*	*z*	*Z*
Ventral MPFC (BA 10/11)	−2	54	−10	3.71*
Ventral MPFC (BA 10)	−6	46	0	4.00*
Dorsal MPFC (BA 9/10)	0	62	20	5.24*
Posterior cingulate cortex	−8	−60	34	5.24*
Left middle/inferior temporal gyrus	−58	−16	−20	3.80*
Left inferior parietal lobe	−44	−54	28	3.60*
Left caudate nucleus	−10	8	12	4.30**
Left superior frontal gyrus	−10	20	60	4.25**
Right cerebellum	24	−86	−38	3.96**

MPFC = medial prefrontal cortex. Ventral MPFC refers to z coordinate ≤ 10 mm and dorsal MPFC to z coordinate > 10 mm.

*Significant at $p < .05$, corrected for multiple comparisons at the voxel level over small volumes of interest (see Methods for details).

**Significant at $p < .001$, uncorrected for multiple comparisons with a minimum cluster size of 20 voxels.

in MPFC. In an attempt to characterize common patterns of brain activation that are observed across diverse task domains, Schmitz and Johnson (2007) have proposed that MPFC supports supramodal processes that appraise the self-relevance of sensory and internally generated (e.g., thoughts, memories) information. In a similar vein, Northoff et al. (2006) and Northoff and Bermpohl (2004) have argued that ventral MPFC is implicated in coding the self-relatedness of information thereby representing it as self-relevant. These propositions fit well with the current findings. When envisioning possible future events, ventral MPFC may evaluate and code the self-relevance of simulations and, more specifically, their relevance to personal goals. We have suggested that this process is a critical component of episodic future thinking that facilitates personal goal achievement (D'Argembeau & Van der Linden, 2007). Firstly, assigning personal value to future-event simulations confers their motivational impact, increasing one's motivation and effort to attain personal goals (Karniol & Ross, 1996; Johnson & Sherman, 1990; Markus & Nurius, 1986). Secondly, representing future states as self-relevant may prompt the mental simulation of the steps one needs to go through to reach one's goal, which leads to appropriate changes in behavior and increases the likelihood that the goal will be reached (Taylor et al., 1998). Thirdly, assigning self-relevance to representations of future events may enable humans to override momentary needs and the tendency toward time discounting and impulsive behaviors in favor of pursuing longer-term goals (Boyer, 2008; Suddendorf & Corballis, 2007; Bechara, 2005). In sum, we propose that when envisioning future events, ventral MPFC may appraise and code the relevance of represented events to personal goals and the self-schema, thereby attaching personal significance to episodic future thought.[1]

Activation of PCC has also been observed in various tasks, including autobiographical memory retrieval (Spreng et al., 2009; Svoboda, McKinnon, & Levine, 2006); navigation and spatial processing (Vogt, Vogt, & Laureys, 2006; Maguire, 2001); and semantic forms of self-knowledge

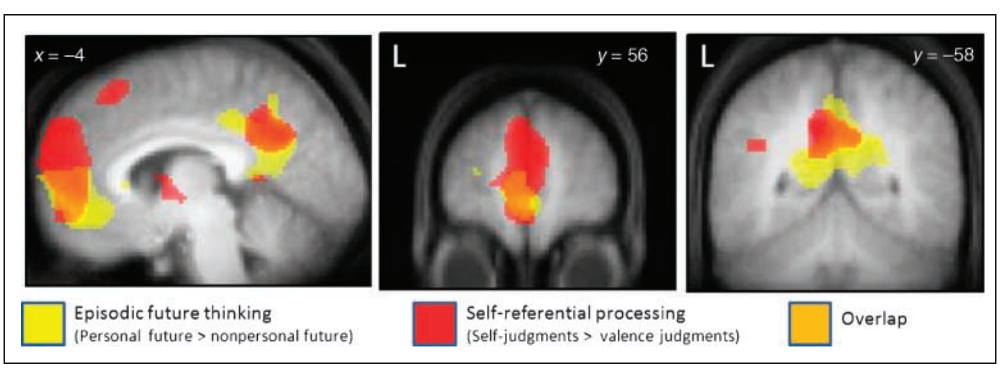

Figure 3. Comparison of self-referential processing in semantic and episodic domains. The brain regions associated with reflecting on one's own personality traits versus making valence judgments (displayed in red) are overlaid on the same image (mean structural MRI of all participants) as the brain regions associated with imagining personal versus nonpersonal future events (displayed in yellow). The two contrasts overlapped (in orange) in ventral MPFC (especially in BA 10) and in PCC.

(D'Argembeau, Feyers, et al., 2008; Johnson et al., 2002; Kelley et al., 2002). Bar (2007) and Bar, Aminoff, Mason, and Fenske (2007) have recently proposed that PCC (along with the medial-temporal lobe and MPFC) is primarily involved in the generation of contextual associations. In this respect, it has been recently found that PCC, parahippocampal cortex, and superior occipital gyrus were more strongly activated when participants imagined future events occurring in familiar contexts (e.g., one's apartment) relative to future events occurring in unfamiliar contexts (e.g., a safari) (Szpunar et al., 2009). Szpunar et al. (2009) suggested that PCC and parahippocampal cortex are involved in reinstating familiar contextual settings from memory during the simulation of future events. Considering those findings, one may wonder whether activation of PCC in the current study could be attributed to the processing of contextual settings. More specifically, it could be argued that personal future events were represented as occurring in familiar contexts more than nonpersonal future events and that activation of PCC reflects such difference in contextual processing. This interpretation does not fit well with the pattern of activation in PCC that was detected across the three types of events, however. Indeed, the imagination of routine activities involved highly familiar contextual settings, yet PCC was less activated when imagining routine activities compared to personal future events. Therefore, we do not think that possible differences in the familiarity of contextual settings can entirely account for the current findings.

It remains possible, however, that the increased activation of PCC when imagining personal versus nonpersonal future events reflects the processing of higher-level contextual associations (Bar, 2007; Bar et al., 2007). Interestingly, Northoff et al. (2006) have suggested that whereas MPFC is involved in coding and reappraising self-relevance, PCC may be implicated in putting self-relevant information in context, integrating it with other self-relevant knowledge. PCC might, for example, mediate associative processes that relate episodic details (mental representations of objects, people, places, and so on) to more general autobiographical knowledge (e.g., abstract representations of long-term goals and associated time periods), thereby contextualizing representations of specific future events within the individual's "life story" (Conway, 2005; Conway & Pleydell-Pearce, 2000). It should also be noted that distinct subregions of PCC might play different roles in future-event simulation. In this respect, Vogt et al. (2006) have dissociated two subregions of PCC and have proposed that ventral PCC interacts with anterior cingulate cortex and ventral MPFC to evaluate self-relevance, whereas dorsal PCC would be more implicated in spatial processing. In the current study, the imagination of personal versus nonpersonal future events was associated with activation that was mainly located in ventral PCC (although it also extended to dorsal PCC). Overall, then, ventral MPFC and ventral PCC may support a collection of processes that together contribute to evaluate, code, and contextualize the relevance of future-event simulations with regard to personal goals and the self-schema.

As we have already mentioned, the network of brain regions that is recruited when envisioning future events has also been associated with autobiographical memory, navigation, and theory of mind (Spreng et al., 2009), and it has been suggested that this core network supports a number of processes that are common to these different tasks (Buckner & Carroll, 2007; Hassabis & Maguire, 2007). Although the precise nature of these shared processes remains to be investigated in detail, the current findings are consistent with the view that some subregions within the core network (i.e., cortical midline structures, and ventral MPFC in particular) support self-referential processes. Activation of the same subregions in other tasks may, in part, be due to the involvement of self-referential processes in those tasks (Spreng et al., 2009). This is most obvious in the case of autobiographical memory tasks as they include a strong self-referential component (Conway, 2005), but activation of ventral MPFC in theory-of-mind tasks may also reflect the use of self-knowledge in order to predict and understand the mental states of others (Mitchell, 2009). Interestingly, tasks that have been associated with the core network but do not involve the type of self-referential processes that were investigated in this study (i.e., navigation tasks) engage many subregions of the core network, but not MPFC (Spreng et al., 2009).

The brain regions implicated in the imagination of future events also correspond to the "default network" (Buckner, Andrews-Hanna, & Schacter, 2008; Gusnard & Raichle, 2001), a network of areas that show decreased activity during a wide range of demanding cognitive tasks relative to passive resting or viewing states (e.g., Mazoyer et al., 2001; Binder et al., 1999; Shulman et al., 1997). The default network is thought to mediate a number of processes that are ongoing during resting states and attenuated when resources are temporarily reallocated to the processing of a particular task (Gusnard & Raichle, 2001). The function of the default network remains to be investigated in detail, but an interesting possibility is that this network instantiates the maintenance of information for making predictions about the future (Raichle, 2006). In a recent and comprehensive review, Buckner et al. (2008) argued that "the fundamental function of the default network is to facilitate flexible self-relevant mental explorations—simulations—that provide a means to anticipate and evaluate upcoming events before they happen" (p. 2). The current findings fit well with this proposition and further suggest that some subregions of the default network (i.e., ventral MPFC and PCC) may be involved in processing the self-relevance of simulations. As can be seen from Figure 2B, the three imagination conditions of this study were associated with decreases of activity in ventral MPFC and PCC relative to passive fixation. Interestingly, however, decreases of activity were less pronounced when imagining personal future events than when imagining nonpersonal future events and routine activities. A possible interpretation of this greater similarity between passive fixation and the imagination of personal future events is that some processes are spontaneously engaged during resting or passive viewing states and are analogous to the processes recruited when simulating personal future events. We propose that such similarity relates to the processing of self-relevance (see also Schneider et al., 2008; D'Argembeau et al., 2005; Gusnard, Akbudak, Shulman, & Raichle, 2001). Specifically, a critical function of ventral MPFC and PCC may be to locate internal information or simulations on a continuum of self-relevance, thereby establishing priorities as to which information should be considered further in order to promote personal goal attainment. As noted by Raichle and Snyder (2007), it is highly unlikely that default network activity is simply a reflection of conscious mental activity (e.g., deliberate evaluation of self-relevance). As we conceive it, however, the processing of self-relevance needs not be conscious and it is likely that processes that help select, maintain, and organize self-relevant information operate below awareness most of the time (Bargh & Morsella, 2008), and may only be accompanied by conscious future-event simulations when increased flexibility is required for guiding behavior (Suddendorf & Corballis, 2007).

To conclude, the current study demonstrates that ventral MPFC and PCC are more activated when imaging future events that are relevant to one's personal goals than when imagining future events that are unrelated to personal goals. These data provide evidence for the role of these brain regions in personal goal processing, a critical feature of episodic future thinking. Activations in overlapping regions of ventral MPFC and PCC were also detected when participants reflected on their own personality traits, suggesting that these brain regions are implicated in self-referential processing across different functional domains (i.e., episodic vs. semantic). We propose that ventral MPFC may be involved in coding and evaluating the self-relevance of mental representations, whereas PCC may be implicated in putting those representations in a broader personal context, for example, by relating them to abstract autobiographical knowledge. Finally, it is suggested that these self-referential processes may be critical components of the function instantiated by the default network of the brain.

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Note

1. It should be noted that although ventral MPFC (BA 10) showed greater activation when envisioning personal versus nonpersonal future events, there was no difference between personal and nonpersonal future events in dorsal MPFC (BA 9), and dorsal MPFC showed greater activation when imagining both personal and nonpersonal future events relative to routine activities (see Table 1). Although some studies have found foci of activation in both ventral and dorsal portions of MPFC during self-referential processing (see Northoff et al., 2006), other studies have observed a selective implication of ventral MPFC and not dorsal MPFC (e.g., Mitchell et al., 2006; D'Argembeau et al., 2005; Kelley et al., 2002). The precise function of dorsal MPFC in episodic future thinking remains to be investigated in detail but the current findings suggest that this region is not involved in processing the self-relevance of imagined events.

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