

## Contextual Processing in Episodic Future Thought

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**Remembering events from one's past (i.e., episodic memory) and envisioning specific events that could occur in one's future (i.e., episodic future thought) invoke highly overlapping sets of brain regions. The present study employed functional magnetic resonance imaging to test the hypothesis that one source of this shared architecture is that episodic future thought—much like episodic memory—tends to invoke memory for known visual-spatial contexts. That is, regions of posterior cortex (within posterior cingulate cortex [PCC], parahippocampal cortex [PHC], and superior occipital gyrus [SOG]) elicit indistinguishable activity during remembering and episodic future thought, and similar regions have been identified as important for establishing visual-spatial contextual associations. In the present study, these regions were similarly engaged when participants thought about personal events in familiar contexts, irrespective of temporal direction (past or future). The same regions, however, exhibited very little activity when participants envisioned personal future events in unfamiliar contextual settings. These findings suggest that regions within PCC, PHC, and SOG support the activation of well-known contextual settings that people tend to imagine when thinking about personal events, whether in the past or future. Hence, this study pinpoints an important similarity between episodic future thought and episodic memory.**

**Keywords:** auto-noetic consciousness, context, episodic future thought, episodic memory, future, mental time travel

The ability to envision specific events that one might encounter in the future—"episodic future thought"—is a fundamental human ability heretofore not much studied empirically (Atance and O'Neill 2001). Recent empirical studies from neuroscience, neuropsychology, and clinical psychology have contributed a preliminary set of findings that implicate a close relationship between episodic future thought and the ability to remember specific episodes from one's past (i.e., episodic memory). Specifically, episodic future thought and episodic memory engage similar neural networks (Okuda et al. 2003; Addis et al. 2007; Szpunar et al. 2007). Moreover, individuals who have trouble recollecting their past are also unable to form detailed mental images of their future, be they people with schizophrenia (D'Argembeau et al. forthcoming), suicidally depressed individuals (Williams et al. 1996), young children (Atance and Meltzoff 2005; Atance and O'Neill 2005; Busby and Suddendorf 2005; Suddendorf and Busby 2005), older adults (Addis et al. 2008), or amnesic patients (Tulving 1985; Levine et al. 1998; Klein et al. 2002; Hassabis et al. 2007).

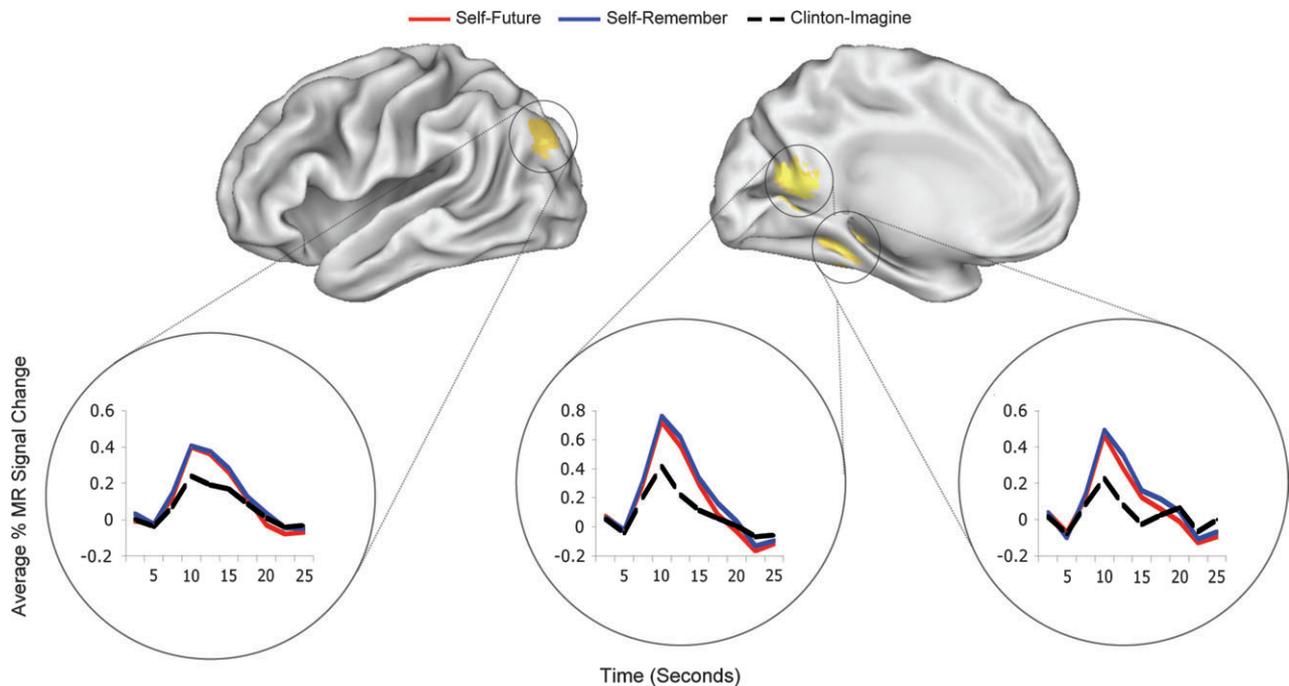
Such consistency in the data has brought about the hypothesis that episodic future thought represents a unique expression of episodic memory, such that the contents of

memory are flexibly sampled and recombined in order to generate novel future scenarios (Schacter and Addis 2007). The present study was designed with the goal of clarifying the underlying nature of this proposed relationship.

Most relevant to the present investigation is a recent functional magnetic resonance imaging (fMRI) study that sought to identify similarities and differences between episodic future thought and remembering (Szpunar et al. 2007). In that study, participants were presented with a series of event cues (e.g., birthday party, road trip, getting lost) (Crovitz and Schiffman 1974; Robinson 1976) and asked to think about those events in one of 3 ways. In one condition, participants were asked to use the cue as a starting point for remembering a specific event from their own lives. In a second condition, the cue was to be used as a starting point for envisioning oneself in a specific future scenario. Similarities in these 2 conditions were identified in relation to a third condition, in which participants were instructed to use the cue as a starting point for envisioning another person engaged in a specific scenario with no temporal reference; specifically, they were asked to envision former US President Bill Clinton engaging in the event (see Addis et al. 2007 for a study with similar logic and conclusions).

Although some regions showed greater activity for episodic future thought than remembering, none showed the opposite pattern (see also Addis et al. 2007). Of most relevance to the present study is a set of regions in posterior cortex that showed indistinguishable activity for episodic future thought and remembering, yet greater levels of activity for both these conditions than the control condition (Szpunar et al. 2007). Specifically, regions within posterior cingulate cortex (PCC), parahippocampal cortex (PHC), and superior occipital gyrus (SOG) all showed robust (and indistinguishable) activity in the 2 conditions that required thinking about oneself at a time other than the present. A representative set of these regions (and their activation patterns) is shown in Figure 1.

Regions within PCC and PHC similar (or identical) to those we considered above appear to play an important role in contextual processing (Bar and Aminoff 2003; Bar 2004, 2007; Aminoff et al. 2007). For instance, one study showed that highly contextualized objects (e.g., a hard hat; associated with a construction zone) engage PCC and PHC to a greater extent than objects not associated with a particular context (e.g., a Rubik's cube) (Bar and Aminoff 2003). In interpreting this and similar patterns of results, Bar (2004, 2007) suggests that PCC and PHC may represent a framework of associative relatedness that helps to generate expectations about what is relevant to a particular situation (i.e., context). The framework easily accommodates the observation that both PCC and PHC are



**Figure 1.** Percent signal change for brain regions exhibiting indistinguishable patterns of brain activity across time while participants envisioned their personal future and recollected the past. Imagining a familiar individual in similar scenarios resulted in a pattern of activity different from both the past and future tasks. Regions appear within (from left to right) superior occipital gyrus (SOG), posterior cingulate cortex (PCC), and parahippocampal cortex (PHC). Adapted from Szpunar et al. (2007).

consistently engaged in studies involving autobiographical memory retrieval and mental navigation of familiar routes (Aminoff et al. 2007), in that these tasks depend upon the reinstatement of familiar contextual settings (see also Epstein and Kanwisher 1998; Sugiura et al. 2005).

It has recently been suggested that these posterior cortical structures are also important for generating the familiar context in which future scenarios are situated (Szpunar et al. 2007; see also Okuda et al. 2003; Addis et al. 2007). That is, one important similarity between episodic future thought and remembering may be that when one envisions a plausible future event it tends to be placed within a well-defined context, typically one that have been experienced in the past (Okuda et al. 2003; Addis et al. 2007; Buckner and Carroll 2007; Schacter and Addis 2007; Szpunar et al. 2007; Szpunar and McDermott 2008, forthcoming). However, because our previous investigation was designed to identify regions that are involved in thinking about oneself in time, the comparison task (imagine another person) necessarily lacked the self-contiguity inherent to mental time travel (Suddendorf and Corballis 1997; Wheeler et al. 1997; Klein 2001; Klein et al. 2002; Tulving 2002, 2005). Accordingly, the neural activity common to personal past and future thought could not be unequivocally attributed to processing of familiar context. Rather, it is also possible that the observed patterns of activity within regions of PCC and PHC reflected self-referential processing (Northoff and Bermpohl 2004; Northoff et al. 2006) or temporal projection (Okuda et al. 2003).

The purpose of the present study was to test the hypothesis that regions of PCC and PHC serve to reinstate familiar context during episodic future thought. An event-related fMRI design was used; participants were required to perform 3 self-referential imagery tasks. In 2 tasks, participants were asked

to imagine themselves (for 10 s) in past (“past familiar” [PF]) or future (“future familiar” [FF]) scenarios that were situated within familiar contexts (e.g., their apartment). In a third task (“future unfamiliar” [FU]), participants were asked to imagine themselves (also 10 s) in future scenarios that were situated within unfamiliar contexts (e.g., safari). Importantly, all 3 tasks required participants to mentally project themselves to a place that is temporally distinct from the present (i.e., each involves self-relevant thought and projection of oneself in time). If PCC and PHC are important for reinstating familiar context, then these regions should show similar patterns of activity when participants are asked to imagine themselves in the context of familiar settings, regardless of the temporal direction (past or future) of the event. Conversely, PCC and PHC should not be engaged to the same extent when participants are asked to imagine themselves in unfamiliar contexts.

## Materials and Methods

### Participants

Participants ( $N = 27$ , 14 males, 13 females, mean age 23.3, range 18–32 years) were recruited from the Washington University community in return for payment. All were right-handed native English speakers with normal or corrected-to-normal vision, and none reported a history of significant neurological problems. Participants provided informed consent in accordance with the guidelines set by the Washington University Human Studies Committee.

### Stimuli

Forty-eight familiar (e.g., apartment, shopping mall, coffee shop) and 24 unfamiliar (e.g., safari, bullfight, hot air balloon) contextual cues were compiled. The 48 familiar contexts were divided into 2 sets and presented in a counterbalanced fashion between the PF and FF orienting cues. The 24 unfamiliar contexts were always presented with the orienting cue FU.

## Procedure

Scans were obtained on a 3-T Siemens Allegra System (Erlangen, Germany) with a standard circularly polarized head coil. A laptop computer running Presentation software controlled the stimulus display via an LCD projector shielded with copper wire, which projected onto a screen placed at the head of the bore. Participants viewed the screen via a mirror fastened to the head coil. A pillow and surgical tape minimized head movement. Headphones dampened scanner noise and enabled communication with participants.

Structural images were acquired using a high-resolution sagittal,  $T_1$ -weighted magnetization prepared rapid gradient echo sequence ( $1 \times 1 \times 1.25$  mm voxels). Functional images (140 per run) were collected with an asymmetric spin echo, echo-planar imaging sequence sensitive to blood oxygen level-dependent (BOLD) contrast (echo time = 25 ms, flip angle = 90 degrees,  $4 \times 4 \times 4$  mm isotropic voxels, volume time repetition [TR] = 2.5 s). In each functional run, whole-brain coverage was obtained with 32 contiguous slices, acquired parallel to the anterior-posterior commissure plane. At the beginning of each run, 4 images were acquired to permit longitudinal magnetization to stabilize; these images were not included in the functional analyses but were used to facilitate alignment of the functional data to the structural images. Each run lasted approximately 6 min, and approximately 1 min elapsed between runs, during which time instructions were given to participants over their headphones.

Three functional runs were conducted for each participant. In each run, participants were presented with a series of 24 contextual cues, each of which was accompanied by an orienting cue. Participants were told to direct their mode of thought on the basis of the orienting cue. Specifically, during each run, participants were required to remember personal memories occurring in the context of familiar settings (PF), to envision personal future events occurring in the context of familiar settings (FF), and to envision personal future events occurring in the context of unfamiliar settings (FU). For example, if the orienting cue PF appeared above the contextual cue apartment, participants would use the cue apartment as a starting point to evoke a specific memory. Some examples were provided to illustrate what would or would not be considered a specific memory (i.e., specific time, place, etc). When a contextual cue was prefaced by the orienting cue FF, participants were asked to imagine a specific event occurring in a familiar context that might reasonably happen to them in the future. When a contextual cue was prefaced by the orienting cue FU, participants were asked to vividly imagine themselves in the future but in the context of an unfamiliar setting. To facilitate cooperation with this task requirement,

participants were presented with contextual cues for which they would be unlikely to evoke a familiar contextual setting (e.g., safari) and were told that the cues represented places that they had likely not been or actions that they had likely not performed; nonetheless, they should attempt to imagine as specific a future scenario as possible. The use of these unfamiliar contextual cues was highly effective. On the basis of an informal posttest questionnaire, only 2 participants reported ever having been physically present within any one of these unfamiliar contexts. These 2 specific trials were excluded from analysis, ensuring that all unfamiliar contexts had not been personally experienced. Each run consisted of 8 PF, 8 FF, and 8 FU trials, and the trials were randomized within each run.

An event-related design was employed (see Fig. 2). Each of the 24 trials within each run began at the onset of the TR. Each trial spanned 4 TRs: the stimulus appeared for 9500 ms, followed by a fixation crosshair for 500 ms. It was explained to participants that the orienting cues would appear in random order and that they should be prepared to switch their mode of thought at any time. On the occasion that participants may not have been able to fully remember or imagine a certain event in the time allotted, they were instructed to let those events out of mind and to focus all their attention on the following trial. However, this was not expected to occur (and in fact did not, as reported by participants following the scan) as the memories and future thoughts could be quite loosely associated with the contextual cues. Participants also encountered 0, 2.5, or 5 s of randomly interleaved fixation crosshairs following each task-relevant trial, introducing temporal jitter into the trial sequence to allow for event-related analyses. During these fixation trials, participants were instructed to give themselves a mental break and remain still.

In all cases, participants were instructed to do their best to perform each task for the entire allotted time per trial. It was stressed that they were not to simply generate a quick memory or image and then stop thinking about it. Instead, they were asked to generate as vivid a recollection or image as possible for the entire 10-s period. It was also stressed that each event should revolve around themselves and their actions and not simply a generic scene. No responses were required. Based on participants' self-report after a prescan practice session, all participants were able to remember or imagine an event to each cue under the specified parameters of the study. Once in the scanner participants were presented with completely novel cues.

It was also explained to participants that they should not close their eyes when thinking about each event. This might have caused them to miss the onset of an upcoming event in the sequence. Finally,

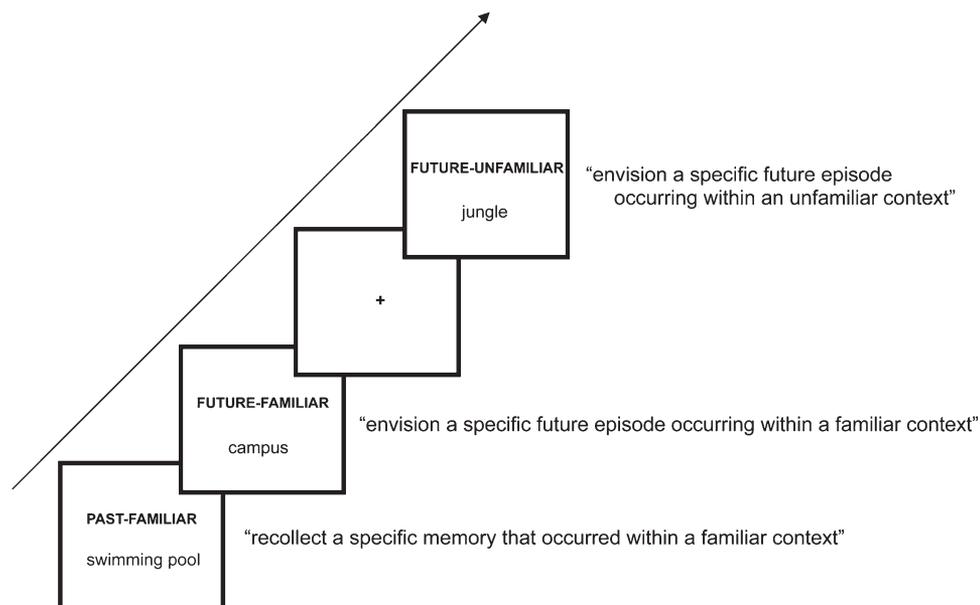


Figure 2. Experimental design.

participants were instructed to remember or imagine events from a first-person perspective. In line with previous research on the relation between past and future thought (Addis et al. 2007), prescan practice revealed that participants were able to comply with this instruction.

### Data Analysis

Data for each participant were preprocessed with the following goals: correction for intensity differences across odd- and even-numbered slices, interpolation to  $3 \times 3 \times 3$  mm voxels, alignment to correct for slice-based within-trial differences in acquisition times, automated movement correction within and across runs (Snyder 1996), removal of the linear slope on a voxel-by-voxel basis to correct for frequency drift (Bandettini et al. 1993), whole-brain normalization to a common mode of 1000 to facilitate comparisons across participants, transformation into standardized atlas space (Talairach and Tournoux 1988), and application of a Gaussian smoothing filter (9 mm full-width half-maximum) to further accommodate variations in activation loci across participants.

Following these preprocessing steps, the data were analyzed using an implementation of the general linear model (GLM; Worsley and Friston 1995). The time course of each condition type (i.e., PF, FF, and FU) was estimated in an assumption-free manner for each subject for each voxel (Boynton et al. 1996); these effects were modeled in the GLM by the 10 time points (i.e., image acquisitions) immediately following each stimulus onset.

### Hypothesis-Driven Analyses

Hypothesis-driven analyses were carried out on a set of 8 posterior cortical regions that had been reported in a previous experiment examining neural responses during personal past and future thought (see Szpunar et al. 2007, p. 644 for a detailed description of how these functionally defined regions of interest [ROIs] were generated). Hypothesis-driven analyses are particularly effective because they use ROIs derived from independent data sets and provide more power due to a decreased number of multiple comparisons and also because of averaging across many voxels within each region.

The ROIs (including peak atlas coordinates; Talairach and Tournoux 1988) were located within left PCC (approximate Brodmann area [BA] 30: -8, -60, 11), right PCC (BA 30: 9, -55, 10), left PHC (2 regions, BA 37: -27, -40, -11; BA 28/35: -17, -39, -9), right PHC (3 regions, BA 36: 24, -37, -8; BA 30: 14, -46, 1; BA 36: -28, -26, -16), and left SOG (BA 19: -34, -77, 29). As discussed in the Introduction, similar (or identical) regions have been implicated in the processing of contextual information. Although less frequently than PCC and PHC, left SOG has been reported in studies of both autobiographical memory retrieval (Svoboda et al. 2006) and mental navigation of familiar routes (Ghaem et al. 1997; Mellet et al. 2000; Rosenbaum et al. 2004). In addition, this region showed the same pattern of activity (past = future > other) as PCC and PHC in prior work (Szpunar et al. 2007). In the current experiment, all ROIs were predicted to show similar patterns of activity during personal past and future thought situated within familiar contexts and relatively little neural activity during personal future thought situated within unfamiliar contexts.

A 2-step analysis approach was adopted to characterize the patterns of activity in these ROIs. All analyses involved averaging across voxels within a given ROI and examining the interaction between conditions of interest and the 10 modeled time points to determine whether the time courses of activity associated with various conditions differed from one another. First, to identify which regions showed activity differences among the 3 conditions, a 2-way repeated-measures analysis of variance (ANOVA) was applied to the average time course data for each of the ROIs. Specifically, this analysis entailed a 3 (condition; PF, FF, and FU)  $\times$  10 (time point; temporal pattern of the BOLD response) ANOVA designed to examine whether differential patterns of activity developed across time for the 3 conditions, which would be manifested by a 3  $\times$  10 interaction.

All regions showing this interaction (i.e., all regions) were further queried with a set of three 2  $\times$  10 ANOVAs. The first of these analyses examined whether thinking about oneself in a familiar context (whether past or future) resulted in similar patterns of activity (which would be manifested by a lack of a 2: PF and FF  $\times$  10: time point

interaction). The final 2 analyses examined whether the ROIs were differentially engaged by familiar context (PF and FF) relative to unfamiliar context (FU). Specifically, these analyses examined whether remembering was differentiated from envisioning oneself in an unfamiliar future context (a 2: PF and FU  $\times$  10: time point interaction) and whether envisioning oneself in the future showed a differential time course of activity as a function of whether the scenario occurred in familiar or unfamiliar context (as would be demonstrated by a reliable 2: FF and FU  $\times$  10: time point interaction).

All significant condition by time point interactions were further qualified by *t*-tests in order to identify the specific time points at which there existed reliable activity differences between conditions.

### Exploratory Whole-Brain Analyses

To further explore the data, 2 maps of voxelwise activity change were constructed in an exploratory manner. Specifically, we cross-correlated the estimated time course of the BOLD response corresponding to each orienting cue at each voxel with a reference gamma function ( $\gamma = 2$  s,  $\lambda = 1.25$  s) that was implemented at 1-s steps to accommodate slight variations in onset time of the response (Boynton et al. 1996). The greatest of the 3 resulting magnitudes (in percent signal change units) were entered into appropriately weighted contrasts. The first map was constructed in order to identify additional regions (other than those considered in the ROI analyses) exhibiting activity differences between familiar and unfamiliar contexts. To this end, we computed a contrast of activation magnitudes for the 2 tasks that involved thinking about oneself in a familiar context (PF [0.5] and FF [0.5]) against the magnitude for thinking about oneself in an unfamiliar context (FU [-1.0]). The second map was constructed in order to directly compare activity differences between past and future thought. To this end, we computed a contrast of activation magnitudes for the task that involved thinking about oneself in a familiar past context (PF) against the magnitude for thinking about oneself in a familiar future context (FF). These 2 tasks were well equated (e.g., self-reference, temporal projection, context) and, thus, well equipped to test prior findings of a general asymmetry in neural activity favoring future thought relative to remembering (i.e., future > past; Addis et al. 2007; Szpunar et al. 2007).

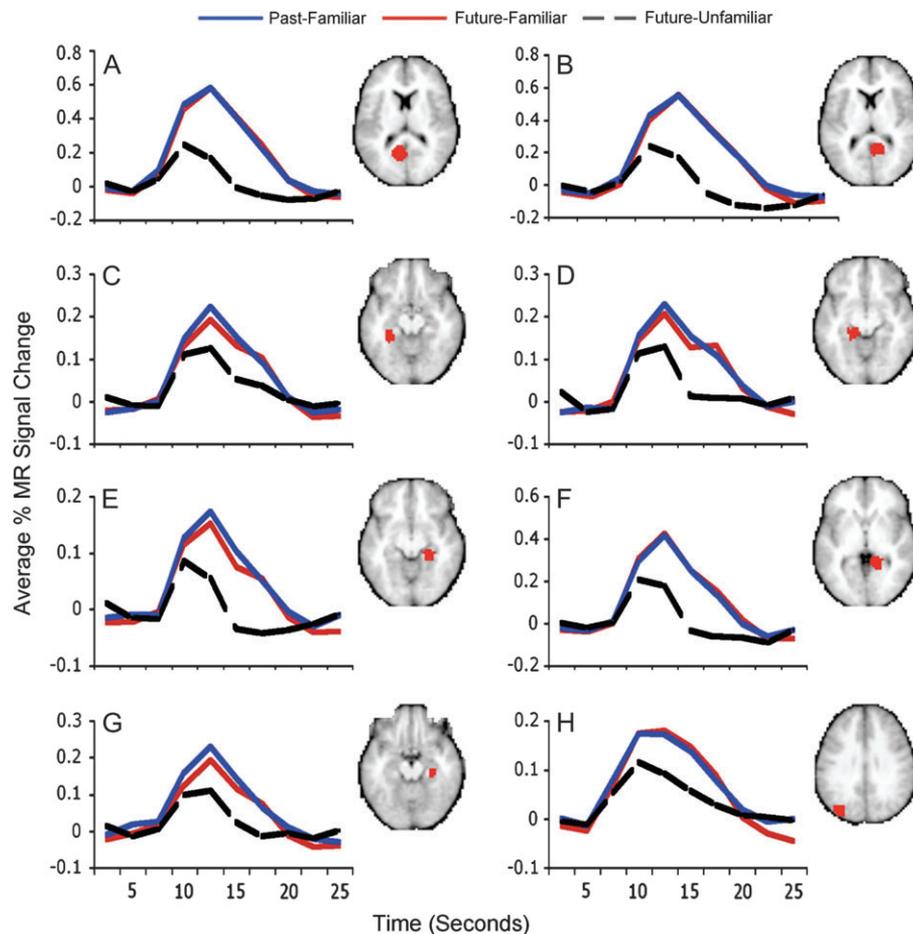
Given the exploratory nature of both comparisons, the resulting images were corrected for multiple comparisons such that  $P < 0.05$ , where  $P$  refers to the probability of a single erroneous activation in the image volume. The correction uses a region size-dependent threshold to guarantee that the experiment-wide Type 1 error is  $< 0.05$ ; specifically, this approach kept only individual voxels exceeding  $P < 0.0001$  that were contiguous with at least 9 other such voxels. An automated peak search algorithm smoothed the group-averaged  $Z$  statistic map using a 5-mm radius sphere; it then identified the location, in atlas coordinates (Talairach and Tournoux 1988), of peak activation on the basis of level of statistical significance with the provision that they be separated by at least 10 mm, or else the peaks were consolidated by coordinate averaging. Regions around the peak activations were identified by choosing contiguous voxels that were within 15 mm of the peak activation and that surpassed the statistical threshold.

## Results

### Hypothesis-Driven Analyses

As can be seen in Figure 3 and Table 1, all 8 ROIs appear to exhibit a similar pattern of activity. To preview, they showed indistinguishable activity in conditions involving familiar context (whether situated in the temporal past or future) and less activity in the condition involving unfamiliar context. This impression is quantified by the statistical analyses. First, for each ROI, the 3  $\times$  10 ANOVA demonstrated that there were differences in the time course of activation among conditions, all  $F_{18,468} > 4.86$ .

To test whether these regions were similarly engaged by familiar context, irrespective of temporal direction (past or



**Figure 3.** Percent signal change for regions from Table 1 showing a statistically indistinguishable pattern of activity across time while participants envisioned their personal future and recollected the past in the context of familiar contextual cues (e.g., apartment). Imagining oneself in the future in an unfamiliar context (e.g., safari) resulted in a pattern of activity different from both the past and future tasks involving familiar contexts.

**Table 1**

Posterior cortical regions showing a significant interaction between condition (PF, FF, FU) and time (temporal pattern of the BOLD response)

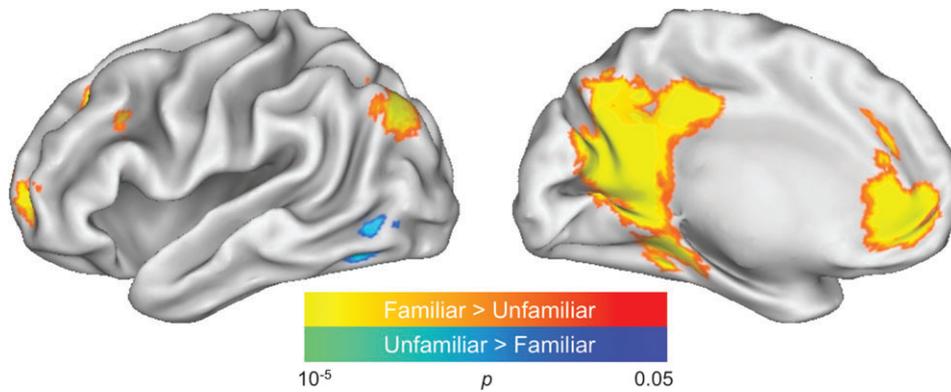
| Figure 3 label   | Region | BA | x   | y   | z   | 2 × 10 ANOVAs             |              |              | Voxels |              |
|------------------|--------|----|-----|-----|-----|---------------------------|--------------|--------------|--------|--------------|
|                  |        |    |     |     |     | 3 × 10 ANOVA              |              |              |        |              |
|                  |        |    |     |     |     | F-ratio <sub>18,468</sub> | PF versus FF | PF versus FU |        | FF versus FU |
| A                | L PCC  | 30 | -8  | -60 | 11  | 24.25                     | 0.51         | 31.53        | 29.75  | 138          |
| B                | R PCC  | 30 | 9   | -55 | 10  | 18.44                     | 0.42         | 22.99        | 23.86  | 119          |
| <i>Temporal</i>  |        |    |     |     |     |                           |              |              |        |              |
| C                | L PHC  | 37 | -27 | -40 | -11 | 5.94                      | 0.90         | 8.97         | 6.90   | 94           |
| D                | L PHC  | 35 | -17 | -37 | -9  | 5.82                      | 0.84         | 7.92         | 7.67   | 88           |
| E                | R PHC  | 36 | 24  | -37 | -8  | 6.43                      | 0.49         | 9.32         | 7.87   | 76           |
| F                | R PHC  | 30 | 14  | -46 | 1   | 11.47                     | 0.60         | 13.73        | 15.23  | 57           |
| G                | R PHC  | 36 | 28  | -26 | -16 | 4.86                      | 0.59         | 6.86         | 6.10   | 33           |
| <i>Occipital</i> |        |    |     |     |     |                           |              |              |        |              |
| H                | L SOG  | 19 | -34 | -77 | 29  | 5.42                      | 0.94         | 4.39         | 9.26   | 88           |

Note: Peak coordinates are reported in standard atlas space. BA, approximate Brodmann's area; L, left; R, right; PCC, posterior cingulate cortex; PHC, parahippocampal cortex; SOG, superior occipital gyrus; PF, Past-Familiar; FF, Future-Familiar; FU, Future-Unfamiliar.

future), the ROIs were more fully characterized by examining the condition (PF and FF only) by time point interaction, which did not approach statistical significance in any ROI, all  $F_{9,234} < 1$  (see Table 1). Finally, we tested whether these regions were differentially engaged by unfamiliar context. Specifically, 2 additional 2 (condition) × 10 (time point) ANOVAs were conducted, each separately comparing familiar context (PF or FF) with unfamiliar context (FU). In each case, our ROIs were

preferentially engaged by familiar context relative to unfamiliar context (PF vs. FU, all  $F_{9,234} > 4.39$ ; FF vs. FU, all  $F_{9,234} > 6.10$ ; see Table 1).

In all regions, time points 5 through 7 exhibited greater activity for the PF condition (all  $t_s > 2.76$ ) and the FF condition (all  $t_s > 2.71$ ), relative to the FU condition. Additionally, the PF condition exhibited greater activity (relative to the FU condition) for time points 3 (region A;  $t = 2.15$ ), 4 (regions



**Figure 4.** Statistical map demonstrating activity across the whole brain for the familiar (past + future) versus unfamiliar context contrast. Colored pixels exceeded the statistical threshold of  $P < 0.05$  (corrected). Activations were predominantly left lateralized (lateral and medial aspect of left hemisphere shown here). The color scales represent the significance level for familiar (relative to unfamiliar) context activations (from red [lowest] to yellow [highest]) and unfamiliar (relative to familiar) context activations (from blue [lowest] to green [highest]).

A-C and E-H; all  $t_s > 2.08$ ), and 8 (regions A and B; all  $t_s > 3.31$ ). The FF condition also exhibited greater activity (relative to the FU condition) for time points 4 (regions A, B, F, and H; all  $t_s > 2.98$ ) and 8 (for regions A, B, and F; all  $t_s > 2.66$ ). There were no reliable differences between conditions PF and FF.

### Exploratory Whole-Brain Analyses

Although the objective of the present study was to directly test the hypothesis that PCC, PHC, and SOG serve to reinstate familiar context during episodic future thought, a few other regions were also preferentially engaged as participants imagined familiar contextual settings, relative to unfamiliar contexts. Indeed, such activity was evident in many regions of the autobiographical memory network (Maguire 2001; Svoboda et al. 2006; Cabeza and St Jacques 2007). In addition to regions of PCC, PHC, and SOG (already identified by the ROI analyses), thinking of past and future events occurring in the context of familiar settings was associated with activity in left frontal polar cortex (BA 10), bilateral dorsal frontal cortex (BA 8), medial frontal cortex (BA 10/32), medial parietal cortex (BA 7), and bilateral inferior parietal cortex (BA 39) (Fig. 4 and Table 2). Percent signal change in these regions confirmed significant activations for familiar context relative to unfamiliar context, which was either associated with deactivations or with minimal activity. In contrast, only left fusiform gyrus (BA 19) became preferentially engaged as participants imagined themselves in the context of unfamiliar settings.

Additionally, past and future events occurring in the context of familiar contexts were directly contrasted. Because these 2 tasks are well equated (e.g., self-reference, temporal projection, context), their contrast was well suited to identify regions that might be preferentially engaged during future (relative to past) thought and vice versa. Replicating previous studies (Addis et al. 2007; Szpunar et al. 2007), we found that a number of regions were preferentially engaged during future thought, whereas no regions were preferentially engaged as participants remembered (Fig. 5 and Table 3). Thinking of one's future was associated with activity in a distributed network of frontal (BAs 6, 11, 45), parietal (BA 40), and temporal (BA 20) cortical regions. These exploratory activations are presented as tentative candidates for future hypothesis-driven investigation. It is interesting to note that these regions (or similar regions)

**Table 2**

Regions identified in the whole-brain analysis contrasting personal events occurring in familiar contexts versus unfamiliar contexts

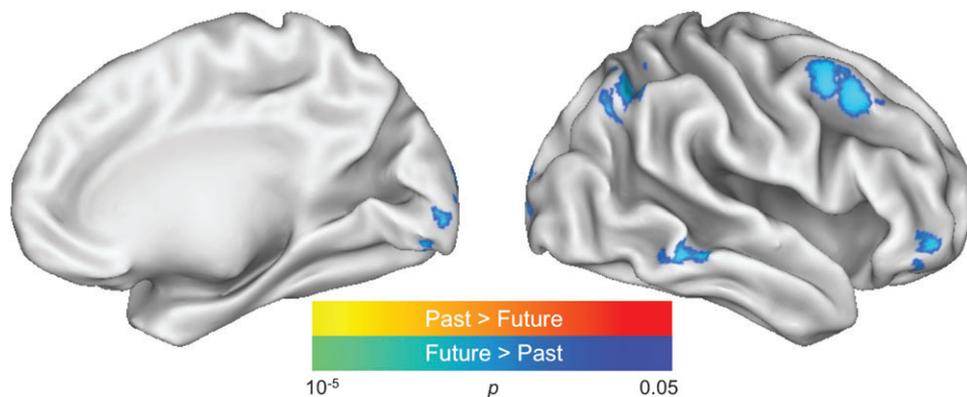
| Region                          | BA    | Coordinates |     |     | Significance level | Voxels |
|---------------------------------|-------|-------------|-----|-----|--------------------|--------|
|                                 |       | x           | y   | z   | z-score            |        |
| <i>Familiar &gt; unfamiliar</i> |       |             |     |     |                    |        |
| Frontal                         |       |             |     |     |                    |        |
| Medial                          | 10/32 | -5          | 45  | 0   | 6.25               | 414    |
| ACC                             | 32    | 3           | 35  | 16  | 5.20               | 77     |
| R superior                      | 6     | 17          | 18  | 51  | 4.79               | 50     |
| R superior                      | 8     | 23          | 30  | 45  | 4.87               | 37     |
| L middle                        | 8     | -20         | 27  | 39  | 5.65               | 115    |
| L medial                        | 9     | -11         | 33  | 27  | 4.65               | 29     |
| L medial                        | 10    | -17         | 51  | 6   | 5.57               | 139    |
| Parietal                        |       |             |     |     |                    |        |
| Precuneus                       | 7     | 1           | -67 | 40  | 5.35               | 281    |
| L TPJ                           | 39    | -44         | -78 | 36  | 5.43               | 95     |
| R TPJ                           | 39    | 47          | -69 | 39  | 4.93               | 50     |
| Temporal                        |       |             |     |     |                    |        |
| L PHC                           | 36    | -20         | -43 | -7  | 5.65               | 122    |
| R PHC                           | 36    | 20          | -36 | -12 | 6.17               | 112    |
| Cingulate                       | 31    | -2          | -33 | 36  | 5.84               | 235    |
| L PCC                           | 30    | -8          | -60 | 15  | 6.30               | 403    |
| R PCC                           | 30    | 8           | -51 | 6   | 5.58               | 364    |
| <i>Unfamiliar &gt; familiar</i> |       |             |     |     |                    |        |
| L fusiform gyrus                | 19    | -43         | -66 | -6  | 4.70               | 35     |

Note: Peak coordinates are reported in standard atlas space. BA, approximate Brodmann's area; L, left; R, right; ACC, anterior cingulate cortex; TPJ, temporal parietal junction; PHC, parahippocampal cortex; PCC, posterior cingulate cortex.

have previously been identified as playing an important role in episodic memory retrieval (McDermott et al. 2000).

### Discussion

To summarize, the present study was designed to test the hypothesis that regions of PCC, PHC, and SOG are involved in reinstating the context within which personal future scenarios are imagined. To this end, we systematically manipulated whether or not participants evoked familiar context when generating novel future scenarios, just as they do when they remember personal memories. Each of these posterior cortical structures was engaged to a similar extent as participants thought about personal events occurring in the context of familiar settings, irrespective of temporal direction (past and future); this finding represents a conceptual replication of Szpunar et al. (2007). Importantly, these same regions showed



**Figure 5.** Statistical map demonstrating activity across the whole brain for the past (familiar context) versus future (familiar context) contrast. Colored pixels exceeded the statistical threshold of  $P < 0.05$  (corrected). Activations were predominately bilateral (lateral and medial aspect of right hemisphere shown here). The color scales represent the significance level for past (relative to future) activations (from red [lowest] to yellow [highest]) and future (relative to past) activations (from blue [lowest] to green [highest]).

relatively little neural activity when participants generated novel future scenarios occurring in the context of unfamiliar settings. We now relate these findings to the relevant literature and discuss their broader implications.

The cooccurrence of PCC and PHC activation has been reported in studies employing the use of a wide range of experimental tasks and is especially pronounced in studies of autobiographical memory retrieval and mental navigation of familiar routes. Those who study autobiographical memory associate PCC and PHC activity with the retrieval of highly specific and detailed memories from one's past (e.g., Addis et al. 2004; Gilboa et al. 2004). On the other hand, those who study mental navigation have associated PCC and PHC function with spatially oriented mechanisms thought to underlie way finding (e.g., Maguire et al. 1996; Mellet et al. 2000; see also Janzen et al. 2007). How do we reconcile the assignment of such seemingly disparate attributions of PCC and PHC functioning?

Recently, Bar and his colleagues (Bar and Aminoff 2003; Aminoff et al. 2007; Bar 2007; Bar et al. 2007) have suggested that the reason PCC and PHC are commonly activated across a wide variety of tasks (including autobiographical memory retrieval and mental navigation) is because such tasks may share common underlying processes. One such process is believed to involve the mind's active generation of contextual associations from memory. Whether one is concerned with remembering a specific memory or mentally tracing the path between 2 familiar locations, our thoughts typically involve well-defined contexts. Bar argues that both PCC and PHC play a role in generating those contexts via associations that have been built up through experience (e.g., the setting of a specific memory is associated with people, objects, emotions, and thoughts that may be typically encountered there).

Here we propose that the neural activity present within regions of PCC and PHC during episodic future thought reflects a similar function as during autobiographical memory retrieval and mental navigation. That is, mental images of personal future events typically occur within the context of familiar settings that are likely drawn from memory (Okuda et al. 2003; Addis et al. 2007; Buckner and Carroll 2007; Schacter and Addis 2007; Szpunar and McDermott 2008, forthcoming; Szpunar et al. 2007). In support of this hypothesis, both PCC and PHC were equally activated, as participants thought about personal events, irrespective of temporal direction (past and future). This finding

**Table 3**

Regions identified in the whole-brain analysis contrasting personal events occurring in familiar past contexts versus familiar future contexts

| Region                  | BA | Coordinates |     |     | Significance level | Voxels |
|-------------------------|----|-------------|-----|-----|--------------------|--------|
|                         |    | x           | y   | z   | z-score            |        |
| <i>Future &gt; past</i> |    |             |     |     |                    |        |
| Frontal                 |    |             |     |     |                    |        |
| L middle                | 6  | -26         | 12  | 51  | 4.33               | 86     |
| R middle                | 6  | 41          | 15  | 48  | 4.86               | 142    |
| R middle                | 11 | 38          | 45  | -9  | 4.30               | 24     |
| L inferior              | 45 | -53         | 24  | 15  | 4.23               | 18     |
| Parietal                |    |             |     |     |                    |        |
| L inferior              | 40 | -47         | -60 | 51  | 4.08               | 70     |
| R inferior              | 40 | 44          | -57 | 45  | 4.29               | 87     |
| Temporal                |    |             |     |     |                    |        |
| R inferior              | 20 | 59          | -45 | -12 | 4.12               | 28     |
| Occipital               |    |             |     |     |                    |        |
| L middle                | 19 | -50         | -78 | -9  | 4.07               | 14     |
| R middle                | 18 | 20          | -99 | 18  | 4.18               | 29     |
| Cingulate               |    | -8          | -30 | 24  | 4.20               | 25     |
| <i>Past &gt; future</i> |    |             |     |     |                    |        |
| None identified         |    |             |     |     |                    |        |

Note: Peak coordinates are reported in standard atlas space. BA, approximat Brodmann's area; L, left; R, right.

replicates previous work (Szpunar et al. 2007) and adds further support to the claim that episodic future thought engages similar processes as those evoked during memory retrieval. Moreover, when participants imagined future scenarios in unfamiliar contexts, PCC and PHC showed relatively little neural activity (this reduced level of activity may represent processing of relatively impoverished associations). This finding further substantiates the claim that past and future thoughts both involve the reinstatement of familiar context from memory (Schacter and Addis 2007; Szpunar and McDermott 2008).

Bar (2004, 2007) suggests that the function of PCC and PHC is not as straightforward as the reinstatement of visual-spatial context per se but rather more high-level contextual associations. Of course, contextual processing is a broad term, and PCC and PHC are likely contributing different subprocesses. Although we cannot adjudicate this issue at this point, future research will surely shed light on the precise functions of PCC and PHC. In addition, SOG activity is often reported in experiments where participants are required to mentally represent a familiar scene (e.g., autobiographical memory, Svoboda et al. 2006; mental navigation, Rosenbaum et al. 2004;

and episodic future thinking, Szpunar et al. 2007). Therefore, it is likely that this region also plays an important role in reinstating context from memory, perhaps through maintaining the mental image (Postle and D'Esposito 1999).

Importantly, all 3 experimental conditions (i.e., PF, FF, and FU) involved aspects of self-referential processing and temporal projection. That is, participants were always required to mentally project themselves to a moment that was distinct from the immediate present. Hence, both self-reference and temporal projection may be unequivocally ruled out in explaining the observed pattern of results.

One alternative explanation is that participants found it more difficult to form a coherent mental image of themselves within the context of unfamiliar settings. However, given that participants were consistently able to generate such scenarios (see Methods), it is not immediately apparent how greater effort on the part of participants would reduce activity within our ROIs. Rather, it seems more reasonable that participants had fewer contextual associations to draw upon when attempting to imagine themselves in unfamiliar settings. A second alternative is that participants may have had equal access to contextual associations across all tasks but that the context associated with unfamiliar (less frequently experienced) settings may have evoked mental representations that were considerably less vivid in detail than those associated with familiar contexts. We believe that this alternative explanation may be ruled out based on some recently reported behavioral data. For instance, in one study, participants not only rated future events occurring in familiar contexts as more vivid than future events occurring in unfamiliar contexts but they also rated their memories as reliably more vivid than any given future scenario (Szpunar and McDermott 2008; see also Johnson and Raye 1981; Johnson et al. 1988). Accordingly, if our ROIs were tracking vividness, one would expect the retrieval of personal memories to engage these regions to a greater extent than the generation of future scenarios occurring in familiar contexts—which was clearly not the case. Furthermore, vividness of mental imagery did not modulate activity within these specific ROIs in a recent study (Szpunar et al. 2007).

### *Generation of Familiar and Unfamiliar Contexts*

In addition to PCC, PHC, and SOG, the act of thinking about oneself in the context of a familiar setting (past and future) recruited other regions that have been reliably associated with the retrieval of autobiographical memories (Maguire 2001; Svoboda et al. 2006; Cabeza and St Jacques 2007). Of particular interest, medial frontal cortex (BA 10/32) was preferentially engaged as participants thought about themselves in familiar (relative to unfamiliar) settings. This outcome was unexpected given that this particular region has consistently been associated with self-referential processing (Gusnard et al. 2001; Johnson et al. 2002; Cabeza et al. 2004). Why would thinking about oneself in the context of an unfamiliar setting not engage this region to the same extent as thinking about oneself in a familiar setting? Although speculative, the present results raise the possibility that medial prefrontal cortex does not underlie self-reference per se but rather the amount of self-referential (or autobiographical) associations that are brought to bear on a particular task (Svoboda et al. 2006). That is, when thinking about familiar contexts, participants are likely also bringing to mind self-relevant information associated with those contexts. This is not likely to be the case as one imagines

a location that is not associated with personal knowledge. Future studies will need to more directly test this hypothesis.

Similarly, it will be important for future studies to directly examine the function of specific regions of the autobiographical memory network and their relation to episodic future thought. On the basis of the present results, we may conclude that this network becomes particularly engaged when episodic future thought takes place in the context of familiar settings. However, elucidation of the role of specific regions (particularly those outside PCC, PHC, and SOG) awaits future hypothesis-driven research.

With regard to imagining oneself in the context of unfamiliar settings, one might hypothesize that this task should rely heavily upon general semantic processing (e.g., imagining what it would be like to be in a jungle). As such, regions associated with general semantic processes (e.g., left inferior prefrontal cortex, Poldrack et al. 1999; McDermott et al. 2003 and lateral temporal cortex, De Renzi et al. 1987; Kitchener and Hodges 1999) might be preferentially engaged as participants generate personal events occurring in the context of unfamiliar settings. However, there was little evidence to suggest that placing oneself in unfamiliar contexts draws upon an additional set of processes (relative to placing oneself in familiar contexts). The only region to show preferential activity as participants thought about unfamiliar settings (relative to familiar settings) was left fusiform gyrus (BA 19). It is unlikely that activity in this region is associated with the quality of the mental image participants had formed as familiar contexts are reliably rated as more vivid than unfamiliar contexts (Szpunar and McDermott 2008). One possibility is that activity in this region was modulated by the distinct nature of the unfamiliar context cues, relative to the familiar context cues (Cohen et al. 2002; McCandliss et al. 2003; Yarkoni et al. 2008).

Based on these preliminary observations, we tentatively suggest that similar processes underlie mental construction of events occurring in the context of familiar and unfamiliar settings. Consistent with this claim, Hassabis et al. (2007) recently presented the case of 5 hippocampal amnesic patients who were unable to imagine themselves in either familiar or unfamiliar settings. Hassabis et al. (2007; see also Hassabis and Maguire 2007) attributed their findings to a deficit in scene construction, which they suggest plays a pivotal role in episodic future thought (among other mental activities that involve placing oneself in a familiar context; e.g., autobiographical memory, mental navigation, cf. Buckner and Carroll 2007). The authors further argue that the binding of contextual associations into a coherent scene is mediated by the hippocampus (Cohen et al. 1999; Eichenbaum 2001). Here we propose that those contextual associations, whether familiar or unfamiliar, are represented within regions of PCC and PHC (Bar 2004, 2007; cf. Eichenbaum et al. 2007). Finally, although familiar settings presumably involve more contextual information, thinking about unfamiliar settings may involve more effort in binding together disparate contextual details. Although we cannot directly address this hypothesis, it represents one possible explanation as to why reliable differences in hippocampal activity were not seen between the familiar and unfamiliar conditions.

### **Conclusions**

The present data fit nicely with a growing body of literature suggesting that the contents of memory are regularly sampled

during episodic future thought (Schacter and Addis 2007; Szpunar and McDermott 2008) and that individuals who have trouble experiencing specific memories from their past (e.g., amnesic patients, young children, older adults) possess a complementary inability to imagine personal future events. That episodic future thought evokes the reinstatement of context from memory provides a starting point for beginning to understand the claim that without memory there can be no vivid future thought.

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