Better imagined: Neural correlates of the episodic simulation boost to prospective memory performance

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Abstract

Episodic simulation is an adaptive process that can support goal-directed activity and planning success. We investigated the neural architecture associated with the episodic simulation improvement to the likelihood of carrying out future actions by isolating the brain regions associated with this facilitation in a prospective memory paradigm. Participants performed a lexical decision task by making word/non-word judgments, with rarely occurring prospective memory target words requiring a pre-specified manual response. Prior to scanning, participants were given exposure to two lists of prospective memory targets: animals and tools. In a fully counterbalanced design, participants generated a rhyme to one target list and imagined their subsequent encounter (episodic simulation) with target words on the other list. Replicating prior behavioral work, episodic simulation improved subsequent prospective memory performance. Brain activation was assessed in a multivariate partial least squares analysis. Relative to lexical decision blocks with no prospective memory demand, sustained prospective memory replicated prior observations of frontal polar activation. Critically, maintaining the intention to respond to simulated targets, over and above rhyme targets, engaged middle frontal and angular gyri, and medial parietal and prefrontal cortices. Transient activity associated with prospective memory target hits revealed activation for simulated targets in medial prefrontal cortex, posterior cingulate, lateral temporal lobe and inferior parietal lobule. In contrast, rhyme target hits engaged more left lateralized dorsolateral prefrontal cortex and anterior insula. Episodic simulation, thus effectively shifts executive control strategy and boosts task performance. These results are consistent with a

Conflict of interests

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growing body of evidence implicating executive control and default network region interactions in adaptive, goal-directed behavior.

People spend considerable time imagining or simulating possible future experiences (D'Argembeau, Renuad, & Van den Linden, 2011). Such *episodic simulation* allows one to mentally "try out" different ways upcoming events might play out without engaging in actual behaviors (cf., Ingvar, 1979; Jing, Madore, & Schacter, 2017; Schacter, 2012) and has been linked with adaptive functions ranging from decision making to emotion regulation (Schacter, Benoit, & Szpunar, 2017). An important but poorly understood question about episodic simulation concerns how it is related to future action (Spreng & Levine, 2013; Szpunar, Spreng, & Schacter, 2014; Szpunar, Spreng, & Schacter, 2016). The formation of intentions to act in the future, and their subsequent execution, is referred to as prospective memory (Einstein & McDaniel, 1990; McDaniel & Einstein, 2007).

Several forms of prospective memory have been identified based primarily upon the nature of the retrieval cue used to elicit the action intention (McDaniel & Einstein, 2007; Shum, Valentine, & Cutmore, 1999). Event-based prospective memory establishes an intention to act in a particular future context (e.g., buy milk while grocery shopping) and has been most closely associated with episodic simulation (Brewer & Marsh, 2010). Future actions are linked to specific event contexts, which can be constructed and elaborated in the present, and subsequently retrieved once the eliciting context is encountered at a future point in time. Consistent with this idea, event-based prospective memory performance is improved by imagining and rehearsing, i.e. simulating, a plan with respect to the specific future context in which it will be executed (Altgassen et al., 2015; Neroni, Gamboz, & Brandimonte, 2014). When the future context is encountered, the intended action is triggered (Chasteen, Park, & Schwarz, 2001; Park, Gutchess, Meade, & Stine-Morrow, 2007; Webb & Sheeran, 2008). The deliberate formation of implementation intentions, or contextually bound if-then contingencies, reliably improves the execution of plans (Gollwitzer, 1999).

Both mnemonic and executive control processes have been implicated in event-based prospective memory (Einstein & McDaniel, 1990; Kopp & Thone-Otto, 2003). Early neuropsychological investigations demonstrated that deficits in episodic memory, associated with hippocampal functioning, predict poor performance on retrospective aspects of future remembering (i.e. generating action intentions, Kopp & Thone-Otto, 2003). In contrast, deficits in executive control processes, associated with frontal lobe functioning, have been associated with the prospective aspects of remembering (i.e. failure to act despite preserved knowledge of the intention (Kopp & Thone-Otto, 2003; McDaniel, Glisky, Rubin, Guynn, & Routhieaux, 1999).

More recently, prospection, or thinking about the future, has been associated with the functioning of a core network of brain regions that overlaps substantially with the default network (Schacter, Addis, & Buckner, 2007). This assembly of functionally connected brain regions has been implicated in a variety of internally-directed mnemonic and associated processes (Andrews-Hanna, Smallwood, & Spreng, 2014; Raichle, 2015), including episodic simulation (Benoit & Schacter, 2015). Because episodic simulation is associated with

enhanced prospective memory (Brewer & Marsh, 2010; Neroni et al., 2014), it follows that the default network may play a role in prospective memory functioning.

However, the role of the default network in active, goal directed control processes, such as prospective memory, remains controversial. Emerging evidence suggests that the default network, through interactions with executive control brain regions, can support cognitive control when access to stored knowledge representations is relevant to task performance (Dixon et al., 2018; Meyer, Spunt, Berkman, Taylor, & Lieberman, 2012; Spreng et al., 2014; Spreng, Stevens, Chamberlain, Gilmore, & Schacter, 2010). Recently we demonstrated that co-activation of default and executive control brain regions is associated with the development of detailed, achievable, and actionable plans towards a desired goal state (Spreng, Gerlach, Turner, & Schacter, 2015; Gerlach, Spreng, Madore & Schacter, 2014). In the context of this autobiographical planning task, default network activity likely reflects the engagement of episodic and associative memory processes to access and reconfigure past experiences into an imagined future goal state (Schacter et al., 2012). Executive control processes are necessary to select and sequence actions, and ultimately evaluate the feasibility of proposed future plans.

Here we investigate whether a similar pattern of default and executive control brain activity would be associated with the role of episodic simulation in facilitating prospective memory performance. We use a standard lexical decision paradigm, with embedded prospective memory probes (Marsh, Hicks, & Watson, 2002). The prospective memory challenge involved infrequent presentations of prospective memory targets that required an alternative response and had been encoded using either episodic simulation or rhyme-based (i.e. non-simulation) strategies. We hypothesized that prospective memory performance would be higher for simulated versus non-simulated targets and, critically, that this facilitation would be associated with co-activation of default and executive control brain regions during the maintenance and realization of the intention. If supported, such a finding would provide initial evidence implicating default and executive region interactions as a neural mechanism underlying the facilitation effect of episodic simulation on prospective memory. Further, these results would provide additional support for an active role of the default network in adaptive, goal-directed cognition.

Methods

Participants

Participants were 30 healthy right-handed young adults (16 females; mean age = 19.9 ± 2.0 years) who gave written informed consent in accordance with the Harvard Institutional Review Board. Three participants were excluded from the neuroimaging analysis due to excessive movement of greater than 4mm framewise displacement. One additional participant lacked recognition data following the prospective memory task because of a technical malfunction and their behavioral data are therefore not included in the subsequent analysis.

Task

Participants completed a version of a lexical decision task previously used to assess prospective memory (e.g. Marsh, Hicks, & Watson, 2002). The task involved classifying letter strings as either words or pronounceable non-words (e.g. "*thistle*" versus "*fivish*", requiring an index versus middle finger button press, respectively). Participants made 720 word/non-word lexical decision judgments. Stimuli consisted of 360 non-words and 360 words and were presented in 12 runs with 5 blocks in each run. Each block was 40s in duration comprising 16 trials, 4 of which were jittered fixation trials. Each task block was interleaved with 20 seconds of fixation.

The prospective memory task was embedded within the lexical decision task, where participants were instructed to respond to words from one of two categories: animals or tools. There were 48 prospective memory trials across all runs, with equal numbers of animal and tool words. Each block was preceded by an instruction to 1) classify words/non-words, 2) classify words/non-words and identify ANIMAL words, or, 3) classify words/non-words and identify TOOL words. One block of each run included the lexical decision task only (12 category blocks in total). The remaining four blocks of each run included the prospective memory instruction. Twenty-four blocks contained from one to three prospective memory target stimuli. Importantly, the remaining 12 blocks of each condition (identify ANIMAL or TOOL words) contained no prospective memory targets. Simulation target, run, and block order were counterbalanced and the trial presentation randomized across participants. Following the prospective memory task, participants completed a forced-choice recognition task with 24 animal and 24 tool distractors to match number of targets in each category.

Pre-Scan Training

Prior to scanning, participants were introduced to the lexical decision task. They were informed that they would see a number of letter sequences, that all of them were pronounceable, and that some letter sequences constituted words, whereas others did not. The task was to classify whether or not each letter string was a word. To indicate a word, participants used their index finger to press the key marked "YES". To indicate a non- word, they used their middle finger to press the key marked "NO". Participants were instructed to make the response as quickly as possible without sacrificing accuracy.

Following the initial exposure to the lexical decision task, participants were then exposed to each list of these 24 target words, one at a time, for ten seconds each. For one category (i.e., animal or tool), participants simulated the upcoming experience of encountering each word for the ten second epoch, and embedded in their simulation a thumb button-press response. Participants were instructed to imagine, in as much detail as possible, what they might think about when the animal (or tool) word appears on the screen. For example, they were told that when the word actually appears, they might think about what the animal looks like, how they might interact with it, their past experiences with that type of animal, and so forth. Participants were instructed to include such thoughts in their visualization of the upcoming encounter with the word. Critically, as part of the simulated encounter, participants were instructed to think to themselves, "When I see the animal word, I am going to press the

button with my thumb". During the pre-scan rhyming exposure condition, participants viewed each word and generated as many rhymes as possible in the ten-second window. This within-subject manipulation ensured equal prior exposure to all prospective memory targets. The rhyme and simulation prospective memory target categories and instruction order were counterbalanced across participants.

Participants were reminded that for the majority of the task, they would be classifying words and non-words and that target words were infrequent. Participants were additionally assured that they would not be shown animal words when instructed to look out for tool words, and vise versa. Button press responses were reviewed, where a "YES" key was pressed with the index finger, and "NO" key with the middle finger to indicate a non-word. Target words required a thumb button press.

MRI acquisition and preprocessing

Brain imaging data were acquired at the Harvard Center for Brain Science with a 3T Siemens TimTrio MRI scanner with a 12-channel head coil. Anatomical scans were acquired using a T1-weighted multi-echo volumetric MRI (TR=2530ms; TE's=1.64, 3.5, 5.36, 7.22ms; 7° flip angle; 1mm voxels). Twelve 4 minute 56 second BOLD functional scan were acquired with a T2*-weighted EPI pulse sequence (TR=2000ms; TE=30ms; 85° flip angle; $3 \times 3 \times 3$ mm voxels with 0.5mm skip).

fMRI data were subjected to standard preprocessing using SPM8 (Wellcome Trust Center for Neuroimaging, London, UK). The first 4 volumes in each run were excluded from analyses to allow for T1-equilibration effects. Data were corrected for slice-dependent time shifts and for head motion within and across runs using a rigid body correction. Images were then spatially normalized to the standard space of the Montreal Neurological Institute (MNI) atlas. The volumetric time series was then spatially smoothed with a 6mm full width half maximum Gaussian kernel resulting in 2mm isotropic voxels. All coordinates are reported in MNI space.

Analysis

Analyses were performed using the multivariate technique partial least squares (PLS), a multivariate functional neuroimaging analysis technique used to identify whole-brain patterns of activity or connectivity that are correlated with tasks (Krishnan, Williams, McIntosh, & Abdi, 2011; McIntosh, Chau, & Protzner, 2004). The statistical significance of the detected patterns is assessed through permutation testing, whereas reliability is determined in an independent step by iterative bootstrap resampling with replacement. We performed three key contrasts of interest. First, we examined the sustained block activity associated with maintaining a prospective memory intention (collapsing across simulation and rhyme targets) over and above the lexical decision task. Second, we examined the sustained block activity associated with maintaining an intention to detect simulated targets versus rhymed targets. For both of these block contrasts, we compared prospective memory blocks (i.e. both simulated and rhymed) where no prospective memory targets were presented. This represents the most conservative contrast as there were no differences in the prospective memory content of the blocks and both task and motor demands were matched

across blocks. Block differences were thus limited to maintaining a specific intention. For the third contrast, we examined transient activity at the individual trial level associated with making a simulation target hit versus a rhyme target hit.

PLS examines changes in brain activity relative to the onset of a block (or trial). To do so, additional processing was performed prior to analysis. Brain activity was normalized to the first TR of a block (or trial), then voxels were averaged across blocks (or trials) within condition. The data matrix is then expressed as voxel-by-voxel deviation from the grand mean across the entire experiment. This matrix is analyzed with singular value decomposition to derive the contrast effects in the data. Here, we applied PLS analysis to assess sustained block activation for word non-word judgments and prospective memory blocks with simulated and rhymed targets. Event-related analysis was used to examine transient trial evoked activity for prospective memory target hits at 5 post-stimulus time points.

For task contrasts, each voxel is given a singular value weight, known as a salience, which is proportional to the covariance of activity or connectivity. The significance of each latent variable as a whole was determined by permutation testing, using 500 permutations. This analysis was accomplished by randomly reassigning the order of the conditions for each participant. PLS is then recalculated for each permutation sample and the frequency with which the permuted singular value exceeds the observed singular values is determined and expressed as a probability. In a second, independent step, the reliability of the saliences for the brain voxels across subjects was determined by bootstrap resampling, using 100 iterations, to estimate the standard errors for each voxel. Clusters larger than 100 mm^3 comprising voxels with a ratio of the salience to the bootstrap standard error values (i.e., the "bootstrap ratio"; BSR) greater than 2.58 ($p < .01$) were reported. The local maximum for each cluster was defined as the voxel with a BSR higher than any other voxel in a 2-cm cube centered on that voxel. PLS identifies whole brain patterns of activity in a single analytic step, thus, no correction for multiple comparisons is required.

Results

Hit rate was higher for simulation targets compared with rhyme targets ($t(29) = 1.80$, $p < .05$ single-tail test, Cohen's d = .33; Figure 1A), consistent with an episodic simulation facilitation effect. When controlling for encoding (i.e. calculating prospective memory target hit rate for only subsequently recognized items), there remained a significant difference between simulation (mean = .74 SD = .18) and rhyme (mean = .69 SD = .20) hit rate (($t(28) = 1.75$, $p < .05$ single-tail test, Cohen's d = .33). Participants also formed a more robust memory of the simulated versus rhymed targets, evidenced by more hits ($t(28) = 4.36$, $p < .001$, Cohen's d = .89; simulation mean = .93, SD = .09; rhyme mean = .83, SD = .15) and fewer false alarms ($t(28) = 2.46$, $p < .05$, Cohen's d = .47; simulation mean = .10, SD = .10; rhyme mean = .15, SD = .14) to simulated target words on an old/new recognition test following the prospective memory task. There was also a significant effect of RT between the three conditions (F(2,28) = 23.62, p < .001, partial eta squared = .63). Post hoc comparisons (Bonferroni correction, alpha .05) revealed that semantic classification (mean = 763.3ms SD = 141.6) was significantly faster in the absence of prospective memory demand.

No differences were observed between the simulation (mean = 804.4ms SD = 150.2) and rhyme (mean = 794.8ms SD = 145.4) conditions for RT during semantic classification.

When we examined the sustained brain activity associated with maintaining a prospective memory intention over and above lexical classification, we found a significant pattern of activity (p = .006). Prospective memory conditions were associated with activation in the frontal poles, lateral prefrontal cortex, supramarginal gyri, and other regions (Figure 1B; Table 1). Relative to prospective memory, lexical classification was associated with greater brain activation primarily in occipital cortex.

Next, we sought to identify brain activity associated with the behavioral facilitation of prospective memory performance conferred by episodic simulation. A significant pattern for brain activity was observed for the simulation blocks, compared with rhyming (p = .048). Sustained activation for simulation target blocks, relative to rhyming blocks, was found in bilateral frontal poles and posterior middle frontal gyrus, medial prefrontal cortex, angular gyrus, medial parietal cortex, and lateral temporal lobes (Figure 1C; Table 1).

Finally, we examined the transient event-related activation associated with successful prospective memory target detection for the simulated versus rhymed targets and found a significant pattern of activation (p = .038). Here we found significantly greater activation in regions affiliated with the default network, including posterior cingulate, medial prefrontal cortex, posterior superior temporal sulcus. Hits for rhymed prospective memory targets were associated with greater left anterior insula, lateral prefrontal cortex and precentral gyrus activation (Figure 1D; Table 1).

Discussion

Previous studies have demonstrated that episodic simulation of a future event can improve prospective memory for that event (Altgassen et al., 2015; Brewer & Marsh, 2010; Neroni et al., 2014). Here we investigated the neural correlates of this behavioral facilitation effect. We first demonstrated that prospective memory hits were more frequent for simulated versus non-simulated targets, replicating the facilitation effect. Next, we examined the effect of episodic simulation on the sustained and transient brain activity, which differentially contribute to prospective memory processes (Reynolds, West & Braver, 2009). During lexical decision task blocks that included a prospective memory challenge we observed a pattern of sustained brain activity in regions typically implicated in prospective memory tasks, including anterior prefrontal brain regions (Burgess, Scott, & Frith, 2003; Reynolds et al., 2009), suggesting a role for frontally- mediated executive control and attentional processes in maintaining an intention. Consistent with predictions, we observed greater sustained activity in anterior prefrontal brain regions covarying with activity in regions associated with the default network (including medial prefrontal cortex and medial and lateral parietal cortex). Finally, we also observed a transient pattern of covarying default and frontal brain activity during prospective memory hits – but only for simulated targets. These results provide initial evidence for the contribution of episodic simulation to prospective memory and identify default-executive interactions as an important neural substrate supporting this episodic facilitation effect.

The multiprocess account of prospective memory retrieval (Einstein & McDaniel, 2005; McDaniel & Einstein, 2000) and episodic simulation theory (Schacter, 2012) implicate both mnemonic and executive control processes in realizing a future intention. Successful prospective memory performance involves mnemonic processes to initially encode the cue and simulate the context in which future intentions will be realized (Schacter, 2012). Mnemonic processes are subsequently engaged to retrieve, reconstruct, and instantiate the simulated intention when the context is re-experienced. Executive control processes are necessary to detect the cue, whether involving preparatory attention and/or cue-driven monitoring (Einstein & McDaniel, 2005, 2010) and initiate episodic retrieval. Inhibitory and switching processes are engaged to cease ongoing actions, switch attentional focus, organize, and implement the intended action. Thus, interactions among default network brain regions, implicated in mnemonic processes (including both spontaneous and strategic retrieval), and frontal brain regions, implicated in executive control processes, may serve as a candidate neural mechanism supporting the facilitative effect of episodic simulation on prospective memory. We have provided evidence consistent with this possibility by implementing a rigorously controlled paradigm to isolate sustained block and transient trial-wise brain activity associated with prospective memory for simulated versus non-simulated events.

Prospective memory targets were detected more frequently for simulated than non-simulated events (Figure 1A), again consistent with earlier reports (Altgassen et al., 2015; Brewer & Marsh, 2010; Neroni et al., 2014). This behavioral difference was associated with reliable differences in brain activity across the two conditions. A pattern of sustained activity, differentiating prospective memory from lexical decision-making task blocks, identified anterior and lateral frontal activations associated with prospective memory (Table 1, Figure 1B), consistent with previous neuroimaging studies (Burgess et al., 2003; Reynolds et al., 2009). We also contrasted sustained activity while maintaining a prospective memory intention for simulated versus non-simulated events. Simulated events engaged core prospective memory regions, including anterior frontal poles bilaterally (Table 1, Figure 1C). Sustained brain activity was also observed in regions of the default network, including medial prefrontal, medial parietal and lateral temporal cortices. While the default network has been implicated in episodic simulation (Benoit & Schacter, 2015), one study linked medial prefrontal cortex with maintaining the details of a delayed intention without an external stimulus to serve as a reminder (Landsiedel & Gilbert, 2015). This suggests that the default network may be actively involved in maintenance of the simulated intention. Critically, this pattern of activity for default and executive control regions differentiated simulated from non-simulated prospective memory blocks despite rigorous matching of these conditions with respect to perceptual and response demands, and in the absence of actually being presented with a target. These findings provide support for our hypothesis that coactivation among executive control and default network brain regions are associated with the facilitative effect of episodic simulation on prospective memory performance.

Additional support for this idea is found in the trial-wise analysis, which examined patterns of transient brain response associated with prospective memory target hits. Reliable differences in brain activity were observed for simulated versus non-simulated target trials. Again, it is important to note that this contrast is tightly controlled to isolate brain

differences associated with prospective memory for previously simulated versus non-simulated targets. Widespread activation of default network brain regions was associated with simulated versus non-simulated targets (Table 1, Figure 1D). When participants successfully responded to a prospective memory target word, only those that had been simulated during the pre-scan training phase elicited default network activation. This pattern of functional brain response closely resembles the findings of a recent meta-analysis examining functional brain activation patterns associated with episodic simulation (Benoit & Schacter, 2015), and suggests that once a prospective memory target is recognized, the pattern of functional brain response entrained during episodic simulation is reinstantiated to support the implementation of the intended action. Based on these findings, we argue that access to episodic simulations is associated with default network activation, and that prospective memory is subsequently facilitated through coordinated default and executive control region activity.

We have recently reported a similar pattern of interactivity among executive and default brain regions during an autobiographical planning task (Spreng et al., 2015). We interpret the current findings as further support for the role of the default network in adaptive goal-directed tasks, when past knowledge of oneself and the world is task relevant. In the context of autobiographical planning, we argued that default network activation facilitated access to stored information and knowledge, which was then fed forward into the service of executive control processes in order to develop future plans. Here we extend the idea that the default network can play an adaptive role in goal directed tasks to a different cognitive context. Specifically, through its role in episodic simulation, and interactions with the executive control regions of the brain, the default network is able to facilitate performance on a goal-directed, prospective memory task.

Finally, we also observed increased engagement of left-lateralized executive control regions associated with the non-simulated prospective memory target hits (Table 1, Figure 1D). While speculative, we suggest that this pattern might reflect a shift in cognitive strategy involving greater requirement to engage control processes of linguistic information in this condition. Previous studies have suggested that other forms of prospective memory, such as time-based, draw more heavily upon executive control resources to detect the eliciting cues for future action (Kopp & Thone-Otto, 2003). In our paradigm, it is possible that without prior episodic simulation to support the subsequent generation of rich, context-based cueing, participants were forced to rely more heavily on executive control and strategic retrieval mechanisms, mediated by frontal lobe brain regions, to gain access to more shallowly encoded prospective memory targets. While we did not predict this result *a priori*, the observation of greater frontal brain activity for more shallowly encoded targets items has potential implications for the design of strategies to remediate prospective memory deficits. Based on our findings and others (Altgassen et al., 2015; Brewer & Marsh, 2010; Neroni et al., 2014), episodic simulation has clear potential utility as an intervention approach to enhance prospective memory performance (e.g., McFarland & Glisky, 2012; Mioni, Bertucci, Rosato, Terret, Rendell, Zamuner & Stablum, 2017; Platt, Kamboj, Italiano, Kendall, & Curran, 2016). However, this approach is time-consuming and taxes memory systems that are often compromised in aging and brain disease, perhaps making it a more challenging and less feasible option for rehabilitation. Our findings, while preliminary,

caution that there may be costs in *not* adopting an episodic simulation approach. Shallow encoding of prospective memory cues may subsequently tax executive control systems (also compromised in aging and brain disease) during the retrieval phase of prospective remembering, leading to retrieval failure. Retrieval failures in real-world settings, in turn, could produce prospective memory errors with more serious functional consequences than those observed in the laboratory. The contribution of functional brain changes, to both retrospective and prospective phases of prospective memory, will be an important area of future research.

Although the simulation and rhyming encoding intervals were matched for word exposure, it is important to note that other differences between the conditions may explain, at least in part, the reported effects. The simulation condition involved simulating the anticipated target stimulus and the appropriate response, and forming an explicit if-then link. These components of the task are central to the episodic simulation, as well as forming the implementation intention to execute this future action. In the simulation condition, participants also probably thought about semantic associations with the target word, and their relationship with self. As a consequence of focusing on semantic features of the targets in one condition, and phonological features in the other, the results could be also attributable to a broader level of processing effect (Craik & Lockhart, (1972). In linking the semantic features of the upcoming word to the self in the context of an episodic simulation, the activation of medial prefrontal cortex can be partially explained (e.g. Kelley et al., 2002). These effects thus may not be specific to episodic simulation. However, episodic simulation is characterized by involvement of the self, and relies upon semantic information (Irish, Addis, Hodges & Piguet, 2012; Irish & Piguet, 2013). Future work is necessary to more specifically examine and attempt to dissociate the role of self-related processes, semantics, temporality, and episodic simulation (e.g. Xu, Yuan & Lei, 2016), to their relationship with goal-directed behavior.

Acknowledgments

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Highlights

- Episodic simulation improves prospective memory performance

- The neural correlates of simulation's boost to PM performance was assessed

- Significant effects were observed for sustained and transient activity

- Default and executive control region activity associated with simulated PM processes
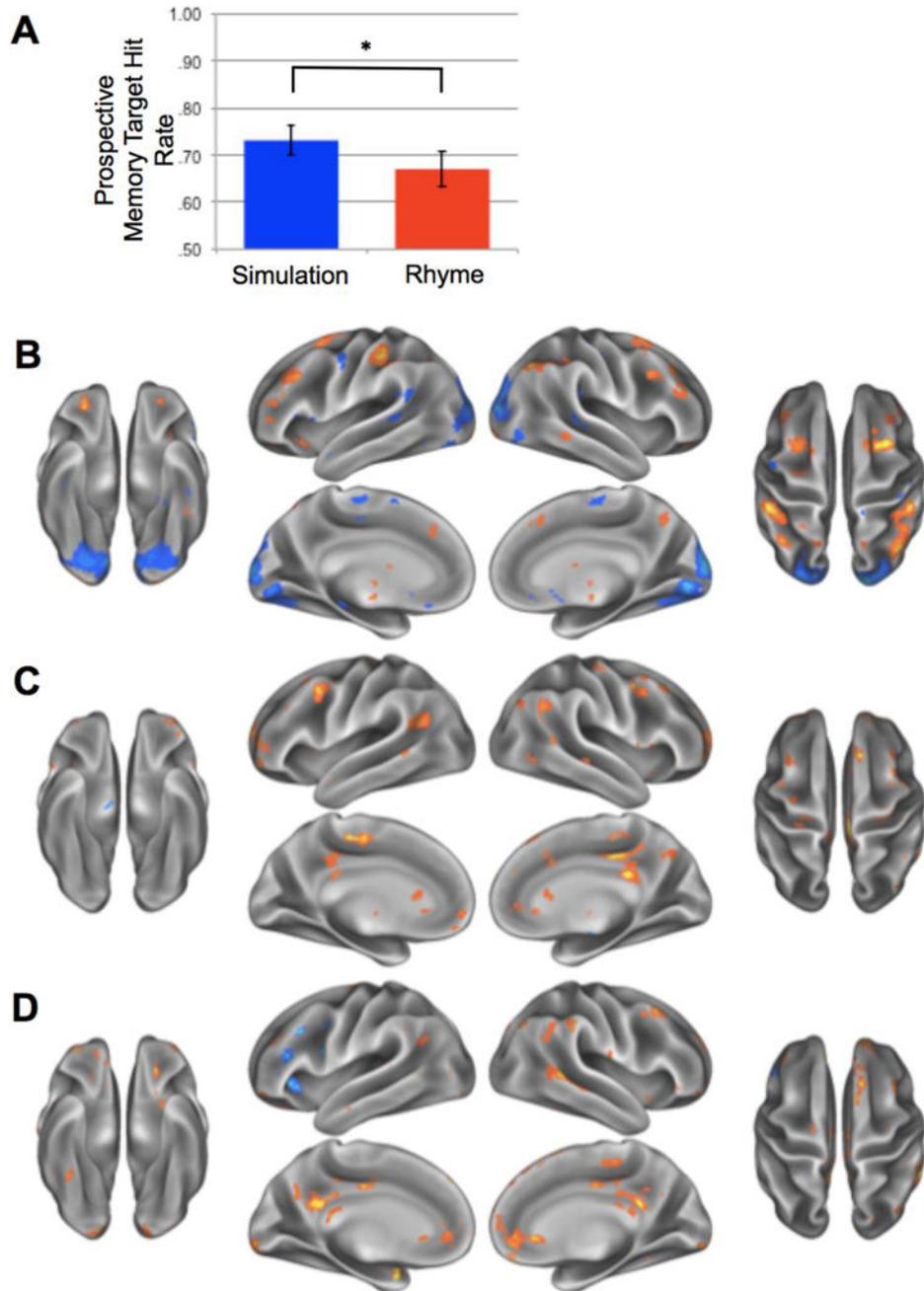
Figure 1.
Prospective memory and the modulatory effect of simulation. A) Hit rate for simulated versus rhymed prospective memory target words. Error bars are SEM. B) Brain activity for sustained prospective memory blocks (warm colors) and lexical decision making (cool colors). C) Brain activity for sustained prospective memory blocks for simulated targets (warm colors) and rhymed targets (cool colors). D) Event-related brain activity for prospective memory target hits: simulated targets (warm colors) and rhymed targets (cool colors).

Table 1

Peak activation coordinates

Region	MNI coordinate			
	x	**y**	**z**	**BSR**
Prospective memory > Lexical decision				
Supramarginal gyrus	−48	−36	44	5.85
Posterior middle frontal gyrus	30	10	52	5.34
Ventral frontal pole	28	48	−14	4.80
Posterior superior frontal gryus	−22	6	58	4.56
Frontal pole	−16	60	8	4.48
Occipital pole	28	−96	−8	4.03
Inferior frontal junction	38	14	34	3.82
Dorsolateral prefrontal cortex	−42	28	34	3.72
Occipital pole	−22	−94	−8	3.71
Precuneus	16	−66	66	3.61
Dorsal anterior cingulate	−10	32	42	3.51
Anterior insula	−30	18	−6	3.49
Dorsolateral prefrontal cortex	44	34	30	3.44
Middle temporal gyrus	60	−40	−8	3.40
Thalamus	4	−10	2	3.28
Ventral temporal cortex	−44	−42	−22	3.23
Frontal pole	−40	44	6	2.98
Lexical decision > Prospective memory				
Dorsal occipital pole	−10	−104	10	−11.42
Postcentral gyrus	46	−18	66	−5.08
Precentral gyrus	−50	−4	−50	−4.31
Medial precentral gyrus	−14	−20	46	−3.94
Angular gyrus	−62	−56	28	−3.91
Superior temporal gyrus	−38	−54	12	−3.85
Inferior temporal gyrus	−50	−26	−22	−3.65
Planum temporale	50	−28	4	−3.43
Ventromedial prefrontal cortex	10	34	−12	−3.21
Simulation > Rhyme block				
Angular gyrus/ posterior superior temporal sulcus	−60	−64	24	5.70
Precuneus	4	−28	48	5.21
Frontal pole	26	66	16	5.11
Middle frontal gyrus	−40	34	40	5.09
Angular gyrus	58	−58	24	4.73
Middle frontal gyrus	46	6	48	4.61
Posterior cingulate cortex	8	−36	26	4.42
Superior frontal gyrus	6	34	58	4.39
Frontal pole	−28	56	18	4.32

Region	MNI coordinate			
	x	**y**	**z**	**BSR**
Inferior frontal gyrus	50	20	0	4.10
Medial prefrontal cortex	6	46	0	3.29
Simulation target hit > Rhyme target hit				
Middle temporal gyrus	−68	−42	6	5.85
Amygdala	−28	2	−18	5.07
Frontal pole	36	58	−10	4.81
Medial prefrontal cortex	2	52	10	4.68
Posterior cingulate cortex	4	−44	24	4.33
Occipital pole	−20	−104	0	4.32
Middle temporal gyrus	62	−46	4	4.22
Superior frontal gyrus	14	24	56	4.19
Ventromedial prefrontal cortex	6	52	−20	3.84
Middle frontal gyrus	−40	32	44	3.82
Posterior middle cingulate gyrus	0	−16	38	3.78
Frontal pole	−38	54	−12	3.49
Superior lateral occipital cortex	28	−84	42	3.14
Rhyme target hit > Simulation target hit				
Midde frontal gyrus	−34	24	20	−3.98
Middle frontal gyrus	−46	18	32	−3.87
Precentral gyrus	−50	2	20	−3.86
Anterior insula	−28	32	0	−3.72
Supramarginal gyrus	−48	−36	44	5.85
Posterior middle frontal gyrus	30	10	52	5.34
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