Constructive Episodic Simulation in Brain and Cognition

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Constructive Episodic Simulation in Brain and Cognition

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Constructive Episodic Simulation in Brain and Cognition

Abstract

A large and growing body of work demonstrates that remembering past events relies on constructive episodic retrieval of event details, while these same processes allow those details to be flexibly recombined into simulations of novel imagined future events, or episodic future thoughts. The present dissertation aims to advance our understanding of the implications of the similarities and differences between episodic retrieval and episodic future thinking. In Study 1, we extend the discussion of these parallels to personality pathology, characterizing self-bolstering tendencies in the episodic retrieval and future thinking of people scoring high in narcissistic grandiosity. In Study 2, we examine the neural correlates of the greater subjective spatial detail during episodic retrieval than during future thinking, finding a distinct set of regions that track spatial detail during retrieval but not future thinking. In Study 3, we draw upon work identifying the contribution of episodic retrieval processes to creativity and use hippocampal-targeted TMS to test whether this region causally supports both creative thinking and episodic simulation. In sum, this body of work broadens our understanding of constructive episodic retrieval, and how it relates to other cognitive processes.

Keywords: episodic retrieval, episodic future thinking, divergent thinking, narcissistic grandiosity, fMRI, TMS

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Chapter 1: General Introduction

A child excitedly recounts their day at school to their parent. Friends share laughter describing stories from work. An artist brushes paint on a canvas, moved by their memory of a traumatic event. A grandparent reminisces about the moment they met their spouse long ago. Interpersonally and culturally, people constantly engage in this unique human experience of remembering personally experienced past events, or episodic retrieval.

Efforts to scientifically parse the phenomenon of episodic retrieval date back over a century. Ebbinghaus (1885) described remembering events as a type of voluntary consciousness to bring back "the seemingly lost states" that are "immediately recognized as something formerly experienced." A century later, Tulving (1985) drew upon this characterization in his description of an *autonoetic* – or self-knowing – *consciousness* that underlies episodic retrieval. That is, there is a unique phenomenal experience of re-experiencing past events that ties the memory to a continuous and veridical experience of the self.

While Tulving's description focuses on veridical remembering, Bartlett (1932) aptly noted that "[i]n a world of constantly changing environment, literal recall is extraordinarily unimportant … [R]emembering appears to be far more decisively an affair of construction rather than one of mere reproduction" (204-205). That is, a memory system that merely reproduces previously experienced events would be largely inefficient given changing environmental demands. Rather, remembering relies on a constructive memory system, in which event details are linked to and influenced by prior knowledge ("schemas" according to Bartlett) that are dynamically reactivated during remembering.

Indeed, empirical data support this constructive account of episodic retrieval. Much of this support comes from characterizing memory errors. While such errors may seem indicative of a malfunctioning memory system, they instead reflect functional and adaptive constructive processes (see Schacter et al., 2011 for review). For example, gist-based memory errors arise when one incorrectly remembers seeing a stimulus they have never seen because it is perceptually or conceptually *similar* to one presented previously (Brainerd & Reyna, 2005; Koutstaal & Schacter, 1997). The Deese-Roediger-McDermott (DRM) paradigm assesses associative memory by presenting participants with lists of semantically-related words (e.g. *sweet, honey, candy*), and testing their memory for these word lists. Importantly, these tests include a *critical lure*, or a word that was not initially presented but is semantically related to the list (e.g. *sugar*). Participants often incorrectly report having seen the critical lure when they in fact did not (Deese, 1959; Roediger & McDermott, 1995; for review, see Gallo, 2010). These errors reflect correct memory for the overarching theme or gist of presented stimuli, which is adaptive for abstracting and generalizing information without retaining extraneous detail that may be unnecessary in more naturalistic contexts (Brainerd & Reyna, 2005; McClelland, 1995; Schacter, 1999).

Another type of memory error is imagination inflation, during which imagining an event increases the false recollection that the imagined event actually occurred (Garry et al., 1996; Loftus, 2003). This effect is greatest with repeated imagination and when sensory detail is incorporated into imagined events (Thomas et al., 2003). Neuroimaging studies have sought to investigate this phenomenon by having participants either view images of objects or imagine images of objects while undergoing functional magnetic resonance imaging (fMRI). Activity in regions supporting visual imagery, like the precuneus, inferior parietal cortex, and fusiform gyrus, corresponded with a judgment of having seen an image of an object, even when the object had only been imagined (Gonsalves et al., 2004; Kensinger & Schacter, 2006). These memory errors underscore the constructive nature of memory and demonstrate that episodic memory and imagined events are supported by overlapping representations. This overlap provides a useful framework for understanding the benefits of a constructive memory system.

Constructive Episodic Simulation

A large and growing body of evidence provides support for the parallels between episodic retrieval of past events, and imagining specific events in one's future, or episodic future thinking (Schacter et al., 2012). Informative parallels between these processes emerge across neuropsychology, behavior in healthy and clinical populations, and neuroimaging.

Early observations from amnesic patients first hinted at such a parallel. Patient K.C. suffered brain damage following a motorcycle accident which left him with large bilateral hippocampal and frontal lobe lesions, and severe episodic memory deficits (Rosenbaum et al., 2005; Tulving et al., 1988). When Tulving asked K.C. what he would be doing the following day, K.C. described his mind as a blank (Tulving, 1985). This observation demonstrated that profound deficits in episodic retrieval could be associated with corresponding deficits in thinking about future events, and thus set the stage for later research on this topic.

Behavioral work has expanded on this initial finding to characterize how episodic retrieval and episodic future thinking induce related phenomenological experiences. Across both the past and future, factors like the valence of the event or how distant in time from the present the event occurs similarly impact phenomenology (D'Argembeau & Van der Linden, 2004). Specifically, positive events are associated with greater feelings of re- or pre-experiencing and contain more sensory detail than negative events, and this relationship holds for both episodic retrieval and episodic future thinking. Events that are closer in time to the present contain greater sensory and contextual detail and generate greater feelings of re- or pre-experiencing than events further from the present, in both the past and future. Individual differences in the features of memory for the past also hold for episodic future thinking (D'Argembeau & Van der Linden, 2006). In addition to these subjective measures of the phenomenology of episodic retrieval and future thinking, parallels between these processes emerge when more objectively evaluating detail using the Autobiographical Interview scoring protocol (Levine et al., 2002). This protocol divides participants' description of a past or future event into *internal details*, which include information pertaining to the episode itself (e.g. time, place, people, happenings), and *external details*, which include information that is not about the central episode (e.g. general semantic context, metacognitive statements). Changes over the lifespan similarly impact episodic retrieval and episodic future thinking: healthy older adults produce fewer episodic details about past events than young adults do, and critically, this effect holds for episodic future thinking (Addis et al., 2008).

A behavioral intervention, the Episodic Specificity Induction (ESI), provides a brief training in recollecting specific episodic details, enabling researchers to manipulate the specificity and detail of episodic retrieval (Madore et al., 2014; Madore & Schacter 2016; for review, see Schacter & Madore, 2016). In the most frequently used version of the ESI, participants watch a video of an event and are oriented to recall specific details about the video. In the specificity induction condition, they are prompted to answer questions about specific episodic detail in the video (e.g. the actions, people, or objects in the video), while in a control condition, the researcher prompts them to simply give their general impressions of the video. Following the ESI, compared to the control induction, participants provide more detail both during episodic retrieval and episodic future thinking. Importantly, the ESI does not impact performance on tasks that do not rely on episodic memory, like describing a picture or generating word definitions (Madore et al., 2014; Madore & Schacter, 2016). This line of work provides evidence that the same episodic retrieval processes that are used to remember past events also underlie episodic future thinking.

Impoverished memories and episodic future thoughts have also been found in studies of various mental disorders. These parallel deficits span across several types of disorders, including anxiety disorders, mood disorders, and psychotic disorders (for review, see Brunette & Schacter, 2021). For example, patients with depression experience overgeneral episodic retrieval (Williams & Dritschel, 1988) and have less specific future thoughts than healthy control participants (Addis, Hach, et al., 2016; Williams et al., 1996). Patients with schizophrenia have less specific and detailed episodic memory retrieval (McLeod et al., 2006) and less specific episodic future thoughts (D'Argembeau et al., 2008; Ben Malek et al., 2019) than healthy control participants.

Another line of evidence for the relationship between remembering the past and imagining the future comes from neuroimaging. Across multiple studies, participants have been prompted to remember specific past events or imagine specific possible future events in their lives while undergoing an MRI scan. A common core network of brain regions, including medial prefrontal cortex, medial temporal lobe, and the posterior midline, are consistently recruited during both episodic retrieval and episodic future thought (Addis et al., 2007; Okuda et al., 2003; Szpunar et al., 2007; see Benoit & Schacter, 2015 for a meta-analysis).

This converging evidence for these key similarities in brain and cognition between episodic retrieval and episodic future thinking led to the development of the *constructive episodic simulation hypothesis*, which states that episodic memory binds component parts of an event, which may later be retrieved or flexibly recombined to construct a representation of a past or imagined future event (Schacter & Addis, 2007, 2020). This recombination process is considered adaptive, as drawing on the past allows one to understand and plan for the future (Schacter & Addis, 2007).

While there are clearly extensive similarities between remembering the past and imagining the future, episodic retrieval and future simulation are not identical processes. Behaviorally, memories for past events are rated as having greater sensorial, spatiocontextual detail than future thoughts (D'Argembeau & Van der Linden, 2004). There are also greater constructive demands during future simulation than episodic retrieval, as the details that compose an event must be flexibly recombined in novel ways (Schacter & Addis, 2007). These demands are mirrored by increased neural activity during future simulation than during episodic retrieval, specifically in the frontal pole and medial temporal lobes, which is thought to reflect these flexible recombination processes (Addis et al., 2007; Okuda et al., 2003; Szpunar et al., 2007). Constructive simulation is a hallmark of both episodic retrieval and future thinking, though task-specific demands may impact the subjective experience and degree of recombination to emphasize differences between these processes.

Contributions of Constructive Simulation to Creativity

Constructive retrieval and simulation not only enable episodic future thinking, but also contribute to other adaptive functions, like creative thinking. *Divergent creative thinking* refers to the ability to combine disparate concepts into novel creative ideas. A common measure of divergent thinking is the Alternate Uses Task (AUT), during which participants are presented with the names of various objects (e.g. a brick) and must generate various creative ways of using them (e.g. as a paperweight) (Guilford, 1967). These responses are then scored according to various metrics, including fluency (how many uses are generated), flexibility (how many categories of appropriate uses are generated), and originality (the novelty of a response, measured by how infrequently it arose in a dataset).

Constructive simulation is thought to contribute to divergent thinking because both processes involve flexibly recombining information into novel combinations, as has been empirically demonstrated through multiple lines of research. Divergent thinking assessed by the AUT, but not performance on a non-episodic control task, is enhanced following an ESI in both young and older adults (Madore et al., 2015; Madore, Jing, et al., 2016). Importantly, the ESI did not impact performance on a test of *convergent thinking* (Mednick, 1962), which assesses the ability to find common associations between objects, highlighting that episodic processes contribute to flexibly finding novel, rather than common, relationships between items.

As previously discussed, constructive episodic simulation can also give rise to predictable patterns of memory errors, and the contribution of constructive memory to divergent thinking is no exception. To characterize this contribution, Thakral et al., (2021) used an individual differences approach, administering both the AUT and the DRM paradigm to the same participants. They found that both false recall and false recognition of the critical lure on the DRM were associated with quantitative measures of divergent thinking (e.g. the *fluency*, or number of uses generated on the AUT), and this result was subsequently replicated in a separate experiment (Thakral et al., 2023). While others have not found an association between divergent thinking on the AUT and false recognition on the DRM, their AUT measure was based on qualitative (e.g. the *originality* of a use), rather than quantitative measures, highlighting the importance of precisely specifying outcome variables when evaluating creative output (Dewhurst et al., 2011).

Neuroimaging results also support this conclusion. Regions of the core network, including the hippocampus and parahippocampal cortex, are jointly engaged during episodic retrieval, episodic future thinking, and divergent creative thinking (Beaty et al., 2018). Following an ESI, participants exhibited greater activity in the hippocampus and greater core network-frontoparietal network connectivity during divergent thinking compared to a control condition (Madore et al., 2019).

Present Dissertation

The current three papers broadly aim to characterize the parallels and differences between episodic retrieval, episodic future thinking, and divergent creative thinking.

As noted earlier, a number of similarities between episodic retrieval and future thinking have been characterized in various mental disorders, including mood disorders, anxiety disorders, and psychotic disorders, However, a domain of psychopathology that has been largely unaddressed in this domain is personality pathology. In Paper 1, we characterize how the similarities between episodic retrieval and future simulation extend to a type of personality pathology, narcissism. Narcissism describes one's ability to maintain a positive self-image; within a healthy range, it can contribute to self-esteem and resilience, though when exaggerated to a level of pathology, leads to self-centeredness, antagonistic behavior, and conflict in relationships (Ronningstam, 2005; Pincus & Lukowitsky, 2010). Pathological narcissism is characterized by dysregulated self-esteem and difficulty maintaining a consistent sense of self, and it can be decomposed into meaningful phenotypes (Cain et al., 2008; Weinberg & Ronningstam, 2022). One such category central to this work is *narcissistic grandiosity*, which is characterized by entitlement, exploitation, and maladaptive behaviors to inflate one's inconsistent sense of self, including engagement in grandiose fantasies about one's life (Pincus & Lukowitsky, 2010).

While some prior work has characterized differences in episodic retrieval that vary with grandiosity (Jones et al., 2017; Ritchie et al., 2015), no one to date has assessed episodic future thought in this population. Paper 1 fills this gap, which is important not only to underscore parallels between episodic retrieval and future thinking consistent with constructive episodic simulation, but also to better understand the potential functions of engaging in episodic retrieval and episodic future thought in enhancing one's self-concept.

Paper 2 and Paper 3 link brain and behavior to further investigate constructive episodic simulation. In Paper 2, we assess the neural correlates of the subjective difference in spatial detail between episodic retrieval and future thinking. While remembered past events are consistently rated as higher in spatial detail than imagined future events (D'Argembeau & van der Linden, 2006), the brain regions that support this heightened subjective detail remain unclear. Few studies report any regions demonstrating greater activity during episodic retrieval than future thinking; those that do are inconsistent. Addis et al. (2009) identified that the retrosplenial complex, parahippocampal cortex, hippocampus, and early visual cortex support a subsystem of the core network linked specifically to remembering. Weiler et al. (2010) found greater activity during memory than future thinking in the inferior parietal lobule, precuneus and early visual cortex. In an effort to reconcile this finding, Gilmore et al. (2016) used an ROI-based approach to identify greater activity during episodic retrieval compared to future thinking in the retrosplenial complex and parahippocampal cortex. While previous work interprets these findings as reflective of the heightened subjective spatiocontexual detail of memory compared to future thinking, they have not incorporated any ratings of spatial detail into their experimental design, so it remains unclear whether these neural differences reflect the subjective spatial detail in an event. Paper 2 advances this prior work by integrating behavioral ratings into the fMRI data analysis, allowing us to directly test which regions track the unique subjective spatial detail of episodic retrieval.

Finally, Paper 3 builds on work identifying the contributions of constructive processes to divergent creative thinking. As described above, neurocognitive similarities between episodic simulation and divergent thinking have been taken as evidence of a role for episodic retrieval in divergent thinking. For example, amnesic patients show deficits in creative thinking (Duff et al., 2013) and common core network regions are active during episodic retrieval, episodic future thinking, and divergent thinking (Beaty et al., 2018; Wu et al.., 2015). One of these common regions of interest is the hippocampus, which is thought to aid with the reinstatement of details retrieved from memory (Thakral, Madore, Addis, & Schacter, 2020). However, the prior work in this domain is correlational, so it is unknown whether the hippocampus and core network causally impact divergent thinking. Paper 3 addresses this question, as we used TMS to disrupt neural activity in the hippocampus and test for a parallel change in divergent thinking performance. By causally testing the role of the hippocampus in episodic simulation and divergent creative thinking, we broaden the understanding of how the constructive memory system is utilized during creative thought.

Taken together, we believe that this body of work contributes to our multifaceted understanding of the utility of constructive memory in future thinking and divergent thinking, while characterizing meaningful task differences to better understand these elaborate processes.

Chapter 2: Paper 1

Grandiose narcissism influences the phenomenology of remembered past and imagined future events

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Abstract

Little empirical work has examined future thinking in narcissistic grandiosity. We here extend prior work finding that people scoring high in grandiosity have self-bolstering tendencies in remembering past events, and we consider whether these tendencies extend to imagining future events. Across an initial study (N = 112) and replication (N = 169), participants wrote about remembered past events and imagined future events in which they embodied or would embody either positive or negative traits. Participants then rated those events on several subjective measures. We find that people scoring higher in grandiosity remember past events in which they embody positive traits with greater detail and ease than past events in which they embody negative traits. These same effects persist when people scoring high in grandiosity imagine possible events in their future. Those scoring higher in grandiosity endorse thinking about positive events in their past and future more frequently than negative events, and they judge positive future events as more plausible than negative future events. These tendencies did not extend to objective detail provided in their written narratives about these events. Taken together, these findings demonstrate that grandiosity is associated with self-bolstering tendencies in both remembering the past and imagining the future.

Keywords: grandiosity, narcissism, memory, future simulation, self-enhancement

Introduction

Narcissistic grandiosity, defined as a sense of self-importance and superiority, is a fundamental component of pathological narcissism (Ackerman et al., 2017; Krizan & Herlache, 2018). People scoring high in grandiosity hold unrealistically positive views of themselves, such as believing they are more intelligent, attractive, and successful than is accurate (for review: Grijalva & Zhang, 2016). Although some self-enhancement can be beneficial (e.g., Taylor, 1989), these self-bolstering beliefs are held even when they cause problems or lead to interpersonal conflict (for review: Morf et al., 2011), and disconfirming evidence of one's grandiosity is often met with devaluation, aggression, or disbelief (e.g., Bushman & Baumeister, 1998; Campbell et al., 2000). This tendency toward self- enhancing beliefs may help explain why high levels of grandiosity, although associated with happiness (Rose, 2002) and well-being (Sedikides et al., 2004; though see Rosenthal & Hooley, 2010 for the confounding role of self-esteem), are also associated with negative outcomes such as interpersonal dysfunction (e.g., Dashineau et al., 2019), substance use (e.g., Welker et al., 2019), and narcissistic personality disorder (NPD) (American Psychiatric Association, 2013). It is therefore important to understand how grandiosity is developed and maintained.

Here, we consider how grandiosity influences the way people recall events from their past (i.e., *episodic memory*; [Tulving, 1983]) and imagine events in their future (i.e., *future simulation*, also referred to as episodic simulation [Schacter et al., 2008] or *episodic future thinking* [Szpunar, 2010]). Both episodic memory and future simulation are strongly implicated in identity formation – a person's sense of self is innately tied to who they believe they were in the past and will be in the future (e.g., Conway, 2005; D'Argembeau et al., 2012; Rathbone & Steel, 2015). In the conceptual framework of a *self-memory system* (Conway & Pleydell-Pearce, 2000), an individual's autobiographical memories exist in tandem with their "working self," comprised of one's goals and self- image (see also Conway, 2005; Conway et al., 2019). The relationship between this autobiographical knowledge and the working self is reciprocal: the working self is derived from autobiographical knowledge and the retrieval of autobiographical episodes is influenced by the working self. Recent work has detailed the role of this self-memory system in self-enhancing biases (see Schacter et al., 2023, for review). For example, Carlson et al. (2020) found that participants in a dictator game that involved sharing money with a partner recalled being significantly more generous than they actually were, and that this self-enhancing bias was most prominent in participants who had been stingy in their allocations. In a developmental study, children as young as 8-to-10 years old showed increased source memory for "nice" action phrases encoded in relation to the self vs. those encoded in relation to others, whereas the opposite was true of "mean" action phrases (Rowell & Jaswal, 2021). These and other findings demonstrate how self-enhancing tendencies[1] in episodic memory are likely contributors to the development and maintenance of an inflated sense of self. Although this work was conducted in the general population, grandiosity exaggerates these tendencies.

Prior research suggests that people scoring higher in grandiosity tend to exhibit self-enhancing tendencies in retrieval of their episodic memories (for summary of event memory in narcissism, see Jones, 2018). For example, people scoring higher in grandiosity (as evaluated by

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[1] Although it is standard practice in the literature to refer to self-enhancing tendencies as self-enhancing biases, here we will use the term "self-enhancing tendencies" when referring to individuals scoring high in grandiosity both because we lack an objective benchmark for accuracy and to avoid pathologizing this population.

the Narcissistic Personality Inventory [NPI; Raskin & Hall, 1979]) exhibited enhanced recall of positive agentic (self-focused, e.g., smart) traits when encoded in relation to the self, but not others; however, this result does not persist for positive communal (interpersonally-focused, e.g., kind) traits (Jones & Brunell, 2014). Moreover, grandiosity was associated with recalling positive agentic memories with more detail and frequency than negative agentic memories (Jones et al., 2017). Of note, this study found these same associations for negative communal traits, suggesting that grandiose individuals' retrieval is modulated by the valence and content of the event. In a study contrasting self-threatening memories with self-bolstering memories, grandiosity was associated with greater use of third-person visual perspective over first-person visual perspective when recalling self-threatening, but not self-bolstering, memories (Marchlewska & Cichocka, 2017), further suggesting a difference in the subjective phenomenology of a memory based on the valence of the event.

These differences in retrieval may also extend to the way that memory affect is retained over time. Ritchie et al. (2015) found that the fading affect bias (i.e., the normal tendency for negative affect to fade more quickly from episodic memory than positive affect [e.g., Walker & Skowronski, 2009]) was exaggerated among those highest in grandiosity for memories in which participants were acting independently. That is, those scoring higher in grandiosity retain the positive affect of these memories to a greater extent than those scoring lower in grandiosity. However, the fading affect bias was reversed among high grandiosity participants for memories in which they were acting cooperatively. Overall, existing literature demonstrates that people scoring high in grandiosity tend to have a self-enhancing tendency in episodic memory, and this may be modulated by the content of the memory itself.

Additional experimental research has identified differences in retrieval of positive feedback over negative feed- back among people high in grandiosity. In one study (Djikic et al., 2005), participants scoring higher in egotistic bias – a proxy for grandiosity – were less likely to accurately recall negative feedback than positive feedback, suggesting a self-enhancing memory distortion. Contributing to the idea that these retrieval differences function to protect the sense of self, Rhodewalt and Eddings (2002) found that a self-enhancing memory distortion among grandiose participants was particularly strong after receiving negative feedback.

Although no research to date has examined whether this self-enhancing retrieval of episodic memories extends to future simulation, cognitive literature suggests that tendencies in episodic memories of people scoring high in grandiosity should be mirrored in their future simulations. A large and growing body of evidence demonstrates that future simulation and episodic memory exhibit striking similarities and rely on common constructive episodic retrieval processes (Schacter & Addis, 2007, 2020). Imagining oneself in the future involves retrieving and combining details that are often extracted from past events (D'Argembeau & Van der Linden, 2006; Schacter & Addis, 2007), and neuroimaging studies demonstrate that a common network of brain regions is implicated in episodic memory and future simulation (e.g., Addis et al., 2007; Okuda et al., 2003; see Benoit & Schacter, 2015 for meta-analysis). Moreover, individual differences found in episodic memory, such as capacity for visual imagery, are paralleled in future simulation (D'Argembeau & Van der Linden, 2006). Parallels between these processes are also found in populations with psychopathology, such as overly generalised episodic memories and future simulations in populations with major depressive disorder, schizophrenia, and post-traumatic stress disorder (e.g., Williams & Dritschel, 1988; Addis, Hach, & Tippett, 2016; Brown et al., 2013; McLeod et al., 2006). Accordingly, given the growing evidence for self-enhancing tendencies in the episodic memories of those scoring high in grandiosity, it might be expected that this population also has self-enhancing tendencies in future simulations.

Clinical literature provides preliminary evidence for future-focused self-enhancement. The mind-wandering content of those higher in narcissism tends to be more positive and future-oriented, as well as more self-revelatory and achievement-focused (Raskin & Novacek, 1991; Kanske et al., 2017). Further, grandiose fantasising – a specific form of self-bolstering future simulation – is a diagnostic criterion and central feature of NPD (American Psychiatric Association, 2013). Psychometric studies have repeatedly demonstrated that grandiose fantasising is a central clinical component of NPD, and the frequency of grandiose fantasising is closely associated with levels of grandiosity (e.g., Di Pierro et al., 2019; Dinić et al., 2021; Clarke et al., 2015).

The present study aims to determine whether there are self-bolstering tendencies in both episodic memory and future simulation of individuals scoring high in grandiosity. We ask participants with varying levels of grandiosity to remember past events and imagine future events in which the participant embodies either a positive trait (i.e., positive events) or a negative trait (i.e., negative events). We not only assess phenomenological ratings of these events, such as subjective ratings of vividness and visual perspective, but also consider other judgments that participants make about the events, including how much difficulty they have generating the event, how frequently they think about that event, and how plausible it is that their future simulation could actually happen. We complement these subjective ratings with measures of objective detail derived from the participants' written narratives about each event.

We predicted that, compared to those scoring lower in grandiosity, people scoring higher in grandiosity would remember and imagine positive events with greater subjective vividness, ease, and first-person perspective than negative events. We further predicted that people scoring higher in grandiosity would rate positive future events as more plausible than negative future events and would report thinking about positive future events more frequently than negative future events. Lastly, we predicted that these results would hold for an objective measure of detail, such that people scoring higher in grandiosity would write with more objective detail about positive events than negative events.

Importantly, this report, and almost all prior related literature, focuses on the grandiose dimension of narcissism, which is characterised by arrogance and entitlement. Narcissism, however, is a multifaceted construct that consists of vulnerability in addition to grandiosity. The vulnerable dimension of narcissism is characterised by feelings of inferiority, fear of failing and losing control (Miller et al., 2021). To ensure a more comprehensive view of narcissism, we include analyses that replace narcissistic grandiosity with narcissistic vulnerability in the Online Supplementary Materials.

Study 1

Methods

Participants

One hundred and twenty participants were recruited from the Harvard University Community and Student Study Pools and participated for payment or course credit, respectively. To meet inclusion criteria, participants were required to be between the ages of 18 and 30 years, live in the United States, report no major mental or physical illness, not take medication that could affect cognitive function, and be native English speakers. Seven participants were removed due to failing more than one attention check, and one participant was removed due to task non-compliance (writing “N/A” during the writing task). This procedure produced a final sample of 112 par- ticipants (58.04% female; Mage = 22.36 (2.69) years), 64 of whom were recruited from the Community Study Pool and 48 of whom were recruited from the Student Study Pool. The sample largely consisted of students (64.29%), and the majority of participants were White (59.82%), fol- lowed by Asian (20.54%). Full demographic information is available in Table S1 in the Supplementary Material available online.

Given the limited prior work in this domain, we estimated a conservative effect size of d= 0.2. Power analyses in G*Power 3.1 (Faul et al., 2009) indicated that an N of 59 would be sufficient to detect a significant effect of our three predictors with 80% power. Since we were primarily interested in the impact of the individual differences in grandiosity on our outcome measures, we doubled this number to ensure that we recruited participants at a broad range of grandiosity, aiming to recruit a sample of 120 participants. Our final sample of 112 participants pro- vided 1344 unique episodic memory and future simulation trials.

Materials

Five Factor Narcissism Inventory – Short Form (FFNI-SF; Sherman et al., 2015). The Five-Factor Narcissism Inventory – Short Form is a 60-item version of the original Five- Factor Narcissism Inventory (FFNI; Glover et al., 2012). Participants rate the degree to which each statement described them on a five-point Likert scale (1 = disagree strongly; 5 = agree strongly). Example statements include: “I aspire for greatness” and “I can talk my way into and out of anything.” The 60 items assess 15 specific narcissistic traits, and these traits are summed to form a total narcissism score. Subsets of the 15 traits are summed to form scores for grandiose narcissism (summed traits: indifference, exhibitionism, authoritativeness, grandiose fantasies, manipulativeness, exploitativeness, entitlement, lack of empathy, arrogance, acclaim seeking, and thrill seeking) and vulnerable narcissism (summed traits: reactive anger, shame, need for admiration, and distrust). Higher scores indicate higher levels of narcissism. The FFNI-SF has been well validated across four diverse samples and shows com- parable reliability and validity to the original FFNI (Sherman et al., 2015). In the present samples, the internal reliability for the grandiose narcissism scale, which is the focus of this paper, was strong (Study 1 Cronbach's alpha = 0.821; Replication Cronbach's alpha = 0.866).

Memory and Simulation Trials. Participants completed 12, two-minute memory and simulation writing trials. Trials were two minutes long so that participants could complete all twelve trials in one sitting. Prior work has also used brief windows (i.e., two to three minutes) for similar tasks (e.g., Addis et al., 2008; Benoit et al., 2016; Lapp & Spaniol, 2017). On six trials, we asked participants to remember and write about an event in their past, and on six trials we asked participants to imagine and write about an event in their future. Each trial was cued by one of twelve, self-relevant adjectives (see Table 1.1) from the English Word Database of Emotional Terms (EMOTE database; Grühn, 2016). Six of these cue words were positively valenced (e.g., skilled) and six were negatively valenced (e.g., inadequate). Of note, both agentic (e.g., smart) and communal (e.g., kind) cue words were included, as well as cue words that are not clearly agentic nor communal (e.g., interesting).[2] To reduce systematic differences between the positive

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[2] Although prior work relating to narcissism and memory has focused on the difference between agentic and communal memories (for review: Jones, 2018), we intentionally included cue words that reflected a range of agency, as we aimed to identify broad, valence-based tendencies in memory and simulation.

and negative categories, cue words were paired across valence category for domain and agency (e.g., smart and stupid; kind and mean; interesting and boring), as well as familiarity. Further, within each valence category cue words were matched for desirability and valence. Familiarity, desirability, and valence were evaluated with ratings from the EMOTE database of emotional adjectives (Grühn, 2016).

The task type (i.e., *episodic memory* vs. *future simulation*) and valence (i.e., positive vs. negative) were counterbalanced such that each participant completed three positive *episodic memory* trials, three negative *episodic memory* trials, three positive *future simulation* trials, and three negative *future simulation* trials. Further, the specific cue words were counterbalanced across these categories, such that each word was equally represented between *episodic memory* and *future simulation* trials. The prompt read as follows:

> Think about a specific event *in your past/in your future* in which you *were/will be* [*cue word*]. Once you have an event in your mind, click next.
>
> Now, describe that *past/future* event (when you *were/will be* [*cue word*]) in as much detail as possible, as if you were playing it through in your mind's eye. Please write this description for the full two minutes. When two minutes have passed, you will automatically be brought to the next screen. Remember to picture and write down all of the event details in your mind, including the people involved, actions, emotions, and what you see, hear, and sense.

A de-identified, representative example of a participant's writing about a positive (cue word: kind) episodic memory is:

> *It was a sunny day. I was volunteering to help facilitate the easter egg hunt that year. I remember how cheerful and happy all the kids looked, nostalgic as I had once been in their very same shoes. Once the whistle sounded, they all ran as fast as they could to collect eggs. One girl dropped all her eggs on the way there. I rushed to help her, and brought some of the extra candy from my car…*

A de-identified, representative example of a participant's writing about a negative (cue word: stupid) future simulation is:

> *I know that at some point in the future I will be stupid while taking a test. I'll be there with a mechanical pencil in my hand, feeling frustrated. I'll feel the heat rush to my face as I do*

not know what to do for the correct answer and almost feel like giving up and so stupid for not knowing the answer. Whatever I'm wearing I'm sure will feel like too much as the room becomes hot and unbearable in my shame…

Table 1.1 *Cue Word Participant and EMOTE Database Ratings*

	Study 1	Replication		EMOTE database	
	Emotional Tone *M* (SD)	Emotional Tone *M* (SD)	Valence *M* (SD)	Familiarity *M* (SD)	Desirability *M* (SD)
Positive Cue Words	5.79 (1.23)	5.91 (1.15)	6.20 (0.39)	5.44 (0.71)	6.49 (0.32)
Admired	6.03 (1.21)	6.17 (1.03)	6.56	5.29	6.70
Interesting	5.68 (1.30)	5.92 (1.16)	6.49	6.51	6.72
Kind	5.66 (1.38)	5.82 (1.26)	6.40	5.73	6.70
Productive	5.62 (1.28)	5.62 (1.21)	6.29	4.77	5.95
Skilled	5.99 (1.05)	6.08 (0.98)	5.60	4.88	6.24
Smart	5.77 (1.12)	5.84 (1.19)	5.83	4.7	6.60
Negative Cue Words	2.78 (1.46)	2.89 (1.63)	2.04 (0.14)	5.01 (0.14)	1.81 (0.32)
Boring	3.18 (1.25)	3.26 (1.46)	2.07	5.81	2.16
Criticized	2.32 (1.04)	2.47 (1.41)	2.06	5.28	2.00
Inadequate	2.27 (1.19)	2.43 (1.43)	1.77	4.00	1.26
Lazy	3.99 (1.85)	4.14 (1.90)	2.18	4.73	1.75
Mean	2.32 (1.28)	2.43 (1.37)	2.06	5.10	1.69
Stupid	2.62 (1.18)	2.60 (1.42)	2.08	5.19	2.02

Note. Study 1 emotional tone ratings are based on participant ratings of the event prompted by that cue word (Study 1 $N = 112$; Replication $N = 169$). EMOTE (Database of English Emotional Terms) database values of valence, familiarity, and desirability are drawn directly from the EMOTE database; standard deviations are not available (Grühn, 2016).

Subjective event ratings. Seven-point Likert-style items were used to assess the phenomenology and other subjective judgments of each episodic memory and future simulation trial. For both episodic memory and future simulation trials, participants reported the difficulty (How difficult was it to remember/imagine this event?; 1 = not at all difficult; 7 = extremely difficult), the vividness of the event (How vivid was your memory/future event?; 1 = not at all vivid; 7 = extremely vivid), the visual perspective of the event (From what visual perspective did you see the event?; 1 = entirely looking through my own eyes; 7 = entirely observing myself from an outside point of view), and emotional tone of the event (Overall, the tone of this memory/future event is …;1 = extremely negative; 7 = extremely positive). For future simulation trials only, participants also rated the simulation frequency (Before this study, how frequently have you thought about this specific event?; 1 = never; 7 = every day) and plausibility of simulation (How plausible is it that this event could take place in your future?; 1 = very implausible; 7 = very plausible).

The adapted Autobiographical Interview. Participants' writing was scored for *objective detail* according to the Autobiographical Interview (AI) scoring protocol (Levine et al., 2002). Briefly, this protocol separates "internal" details, which are episodic details produced about the event of interest, from "external" details, which are non- episodic details provided by the participant, including general knowledge giving context to the event, metacognitive statements, repeated details, and references to other events. We utilised an automated version of this scoring protocol, which tailors an existing language model to predict the number of internal and external details in an event narrative and has been shown to be positively correlated with results from traditional manual scoring of the AI (Van Genugten & Schacter, in press).

The model performance of this automated scoring procedure was calculated by taking a subset of 60 manually scored past and future events and correlating these manual internal and external detail scores with those derived from the automated scoring method. Internal detail classification was correlated at r(58) = .62, p < .001, and external detail scores were correlated at r(58) = .32, p = .01, which are in line with correlations from previous studies (Van Genugten & Schacter, in press). Importantly, rates of misclassification of details, assessed by looking at the correlation between internal details from the auto- mated scoring and external details from the manual scoring, and vice versa, were not significant (r(58) = -.07, p = .58, and r(58) = .15, p = .26, respectively). The reliability of these scoring methods was assessed by normalising the manual and automated scores of the 60 events, then conducting intraclass correlation (ICC) analyses employing a two-way random effects model. Reliability was moderate for internal details, ICC(2,2) = .63, 95% CI [0.45 - 0.76], and poor for external details, ICC(2,2) = .33, 95% CI[0.08–0.54].

Procedure

Participants completed the study online via Qualtrics. Following informed consent, participants completed self- report questionnaires, including the FFNI-SF (Sherman et al., 2015). Participants then completed 12 memory and simulation trials, each of which was followed by subjective event ratings. Lastly, participants completed additional questionnaires, provided feedback on the study, and watched a mood boosting video. Altogether, the study took approximately one hour.

Analytic Plan

This protocol was approved by the Harvard University Institutional Review Board (Protocol: IRB21-0616). De- identified data and reproducible code are publicly available at:

https://github.com/sekalinowski/simulation-biases-grandiosity. Additional study materials are available in the online Supplementary Material. We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study. Data were analysed using R (RStudio version 1.4.1717).

To test our main hypotheses, we ran a series of linear mixed effects models using the *lmer* function in the *lmerTest* package in R. These models were used to predict the subjective ratings from each event (i.e., *difficulty*, *vividness*, *visual perspective*, *frequency*, and *plausibility*) and the objective detail derived from participants' written narratives. Each prediction model included an interaction term between grandiosity (as assessed by the grandiose narcissism score of the FFNI-SF) and valence of the cue word (positive or negative), and random effects of participant ID and cue word. For the outcomes that applied to both past and future events (*difficulty*, *vividness*, *visual perspective*, *internal detail*, and *external detail*), task (i.e., *episodic memory* vs. *future simulation*) was also included in the interaction term. Due to a software error, five *vividness* ratings, two *visual perspective* ratings, one *frequency* rating, two *plausibility ratings*, and four *emotional tone* ratings were not recorded. Therefore, they were excluded from analyses. The statistical significance of all models was corrected for multiple comparisons using the False Discovery Rate (FDR) correction.

We conducted exploratory analyses completing all above analyses with narcissistic vulnerability replacing narcissistic grandiosity. Additionally, we conducted an exploratory analysis of the agency of cue words. Trials that were cued by a positive agentic word (smart), a negative agentic word (stupid), a positive communal word (kind), and a negative communal word (mean) were selected. Using this subset of data, we tested for a three-way interaction between grandiosity, valence, and cue word type (agentic vs. communal) in predicting all main outcomes. Participant ID was included as a random effect.

Given that most outcome variables are Likert items, we corroborated the results of all linear models by running them within a model formulated for ordinal data, implemented using the *clmm* function in the *ordinal* package in R. The effects of interest were consistent across linear and ordinal models, so we report the linear regression results here for ease of interpretability. We evaluated whether our models met the assumptions of linear mixed effects models. Overall, models clearly met assumptions of linearity, normality of residuals, multicollinearity, and outlier testing. Models performed reasonably well on evaluations of heteroscedasticity.

Results

Descriptive Statistics

Participants' grandiose narcissism scores (FFNI-SF grandiosity) ranged from 56 to 179 (M= 119.44, SD = 26.07). To check our cue word valence manipulation, we evaluated the influence of cue word valence (positive vs. negative) on participants' ratings of *emotional tone* of events. On average, positive word cued events were rated as 5.79 (SD = 1.23) and negative word cued events were rated as 2.78 (SD = 1.46). A linear mixed effects model confirmed that the cue word manipulation worked as intended, as the valence of the cue word predicted the emotional tone ratings of the resulting events ($\beta = 3.01$, 95% CI [2.87–3.15], $p < .001$).

Primary Analyses

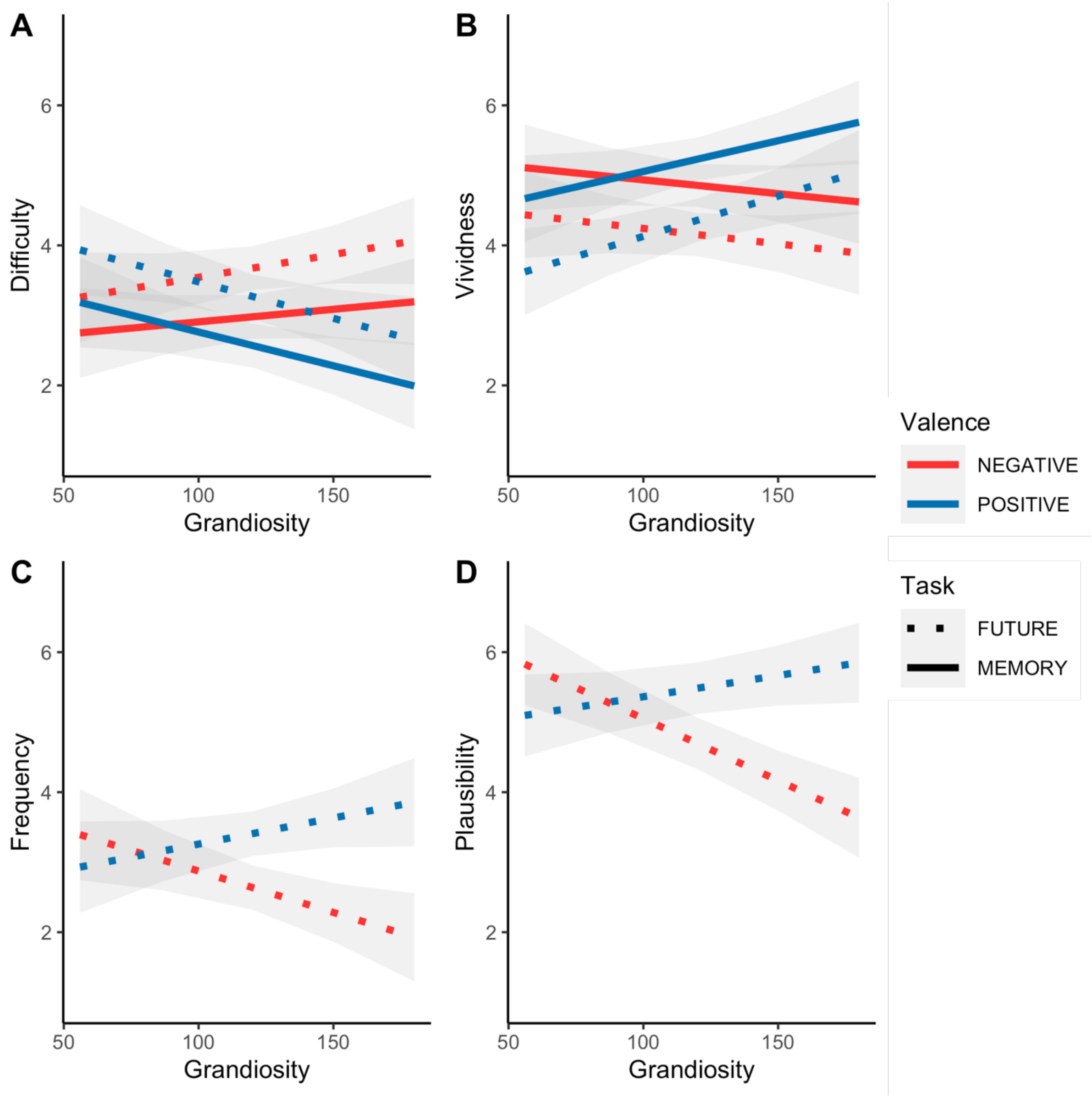
Full output of subjective rating models is reported in Table 1.2. As predicted, we found a significant interaction of grandiosity and valence on *difficulty* ratings, such that participants scoring higher in grandiosity found negative events across both past and future more *difficult* to remember and imagine than positive events, compared to those scoring lower in grandiosity (β = −0.02, 95% CI [−0.03 – −0.01], p_{fdr} = .001; Figure 1.1(a)). We found this same effect for *vividness* ratings, as people scoring higher in grandiosity rated positive events as more *vivid* than negative events, compared to those scoring lower in grandiosity (β = 0.02, 95% CI[0.01–0.02], p_{fdr} <.001; Figure 1.1(b)). Further, we found the same effect for *visual perspective* ratings (β = −0.01, 95% CI[−0.02–0.00], p_{fdr} = .004; Figure S1.1), such that people scoring higher in grandiosity reported greater use of third-person perspective for negative events than positive events, compared to those scoring lower in grandiosity. This interaction of grandiosity and valence was also present for *frequency of simulation* ratings, as people scoring higher in grandiosity reported simulating positive future events more *frequently* than negative events, compared to those than scoring those lower in grandiosity (β = 0.02, 95% CI [0.01–0.03], p_{fdr} <.001; Figure 1.1(c)). Finally, we found an impact of this same interaction on *plausibility* ratings, such that people scoring higher in grandiosity reported that the positive future events they generated were more *plausible* than the future negative events, compared to those scoring lower in grandiosity (β = 0.02, 95% CI[0.02–0.03], p_{fdr} <.001; Figure 1.1(d)).

Table 1.2 *Study 1 Linear Mixed Effects Model Output for Subjective Rating Analyses*

	Difficulty				Vividness				Visual Perspective				Simulation Frequency				Plausibility			
Predictors	β	95% CI	*p*	p_{fdr}	β	95% CI	*p*	p_{fdr}	β	95% CI	*p*	p_{fdr}	β	95% CI	*p*	p_{fdr}	β	95% CI	*p*	p_{fdr}
(Intercept)	2.89	1.79, 3.99	**<.001**	**<.001**	4.68	3.63, 5.74	**<.001**	**<.001**	2.26	0.94, 3.59	**.001**	**.001**	4.06	2.94, 5.17	**<.001**	**<.001**	6.82	5.89, 7.76	**<.001**	**<.001**
Grandiosity	0.01	-0.00, 0.02	.147	.184	-0.00	-0.01, 0.00	.304	.304	0.01	-0.00, 0.02	.127	.185	-0.01	-0.02, -0.00	**.010**	**.026**	-0.02	-0.02, -0.01	**<.001**	**<.001**
Valence (pos)	1.63	0.44, 2.81	**.007**	**.007**	-1.71	-2.79, -0.62	**.002**	**.005**	1.60	0.48, 2.71	**.005**	**.007**	-1.54	-2.65, -0.43	**.007**	**.007**	-2.07	-3.18, -0.95	**<.001**	**.002**
Task (memory)	-0.34	-1.49, 0.81	.559	.768	0.65	-0.40, 1.69	.225	.674	0.17	-0.95, 1.28	.769	.769								
Grandiosity x Valence	-0.02	-0.03, -0.01	**<.001**	**.001**	0.02	0.01, 0.02	**<.001**	**<.001**	-0.01	-0.02, -0.00	**.004**	**.004**	0.02	0.01, 0.03	**<.001**	**<.001**	0.02	0.02, 0.03	**<.001**	**<.001**
Grandiosity x Task	-0.00	-0.01, 0.01	.541	.812	0.00	-0.01, 0.01	.912	.912	-0.00	-0.01, 0.00	.334	.812								
Valence x Task	-0.45	-2.08, 1.18	.588	.588	0.55	-0.92, 2.02	.463	.588	-1.48	-3.05, 0.10	.066	.198								
Grandiosity x Valence x Task	0.00	-0.01, 0.02	.585	.605	-0.00	-0.02, 0.01	.605	.605	0.01	-0.00, 0.02	.070	.211								
Random Effects																				
σ^2	2.62				2.14				2.46				2.25				2.07			
τ_{00}	$0.66_{\text{subjectID}}$				$0.69_{\text{subjectID}}$				$1.51_{\text{subjectID}}$				$0.83_{\text{subjectID}}$				$0.33_{\text{subjectID}}$			
ICC	0.07_{stim}				0.07_{stim}				0.00_{stim}				0.07_{stim}				0.15_{stim}			
	0.22				0.26								0.29				0.19			
N	12_{stim}				12_{stim}				12_{stim}				12_{stim}				12_{stim}			
	$112_{\text{subjectID}}$				$112_{\text{subjectID}}$				$112_{\text{subjectID}}$				$112_{\text{subjectID}}$				$112_{\text{subjectID}}$			
Observations	1344				1339				1342				671				670			
Marginal R^2 / Conditional R^2	0.058 / 0.263				0.070 / 0.314				0.015 / 0.389				0.063 / 0.331				0.095 / 0.266			

Note. p_{fdr}= *p*-values following False Discovery Rate multiple comparisons correction. Grandiosity = Grandiosity score from the Five-Factor Narcissism Inventory - Short Form. Valence = positive vs. negative cue word. Task = episodic memory vs. future simulation. Blank cell indicates that element is not applicable.

Figure 1.1 *Study 1 Subjective Rating Models*



Note. This figure depicts the fitted estimates of linear mixed effects models in which an interaction term between grandiosity and cue word valence (positive vs. negative) predicts subjective ratings of events (A. Difficulty [1 = not at all difficult; 7 = extremely difficult]; B. Vividness [1 = not at all vivid; 7 = extremely vivid]; C. Frequency with which one has previously thought about this event [1 = never; 7 = every day]; D. Plausibility [1 = very implausible; 7 = very plausible]). Panels A and B include task type (episodic memory vs. future simulation) in the interaction term. Random effects of participant ID and cue word are included in all models. Grey area represents 95% confidence intervals. Grandiosity = Grandiosity subscale total score of the Five-Factor Narcissism Inventory-Short Form. All pictured models are replicated in the Replication Study.

We next assessed how grandiosity and event valence predict the amount of *objective detail* in past and future events, as scored by the automated AI. Table S1.2 in the Supplementary Materials available online presents full output of objective detail models. With the use of the automated scoring system validated for the present dataset, we tested for an interaction of grandiosity and valence on internal and external details. We found that neither the amount of internal detail nor the amount of external detail in a past or future event was significantly predicted by the interaction between grandiosity and event valence (Internal detail: β = 0.07, 95% CI[−0.07–0.21], p_{fdr} =.665; External detail: β =−0.01, 95% CI[−0.14–0.11], p_{fdr} =.831). This lack of an interaction between grandiosity and event valence persisted even when we used different measures of objective detail, internal and external density. Internal and external density control for the impact of verbosity by dividing the detail count in each category by the word count of the event (Spreng et al., 2018; Lockrow et al., 2023).

All significant interaction effects between grandiosity and valence remained significant (all ps$_{fdr}$ < .01) when including a covariate of potential confounding variables. These variables included self-esteem (as measured by total score of the Rosenberg Self Esteem Scale [RSES; Rosenberg, 1965]), depression symptoms (as measured by the depression subscale of the Depression and Anxiety Stress Scale-21 [DASS-21; Lovibond & Lovibond, 1995]), anxiety symptoms (as measured by the anxiety sub- scale of the DASS-21), visual imagery capability (as measured by the Vividness of Visual Imagery Questionnaire [VVIQ; Marks, 1973]) and fantasy proneness (as measured by the Creative Experiences Scale [CEQ; Merckelbach et al., 2001]). These significant interaction effects between grandiosity and valence all remained significant when conducted through ordinal mixed effects models.

Exploratory Analysis

All subjective rating and objective detail analyses replacing grandiosity with vulnerability are available in Tables S1.3 and S1.4 of the Online Supplementary Materials. As predicted, following corrections for multiple comparisons, no significant main or interaction effects were found.

In the subsample of trials cued by representative agentic words (smart; stupid) and communal words (kind; mean), we found that cue word type (agentic vs. communal), grandiosity, and valence did not significantly interact to predict any outcomes of interest (all $ps_{fdr} > .05$; for full model output, see Table S1.5 in the Supplementary Material available online). This result suggests that the interaction effects of grandiosity and event valence are not significantly influenced by whether the cue words evoked agentic or communal events.

Summary

Taken together, these results indicate that, compared to people scoring lower in grandiosity, people scoring higher in grandiosity remember past events and imagine future events in which they embody positive traits with greater vividness and ease than events in which they embody negative traits. Further, participants scoring higher in grandiosity believe positive future events are more plausible than negative events and think about them with greater frequency. As predicted, there were no significant three-way interactions, suggesting that these tendencies are consistent across memory for the past and imagination of the future. To bolster confidence in these findings, we conducted a replication study with a new sample.

Replication Study

Methods

Participants

Participants for the Replication were recruited through Amazon's Mechanical Turk (MTurk) via CloudResearch (Litman et al., 2017). Inclusion and exclusion criteria were identical to those in Study 1. Of the 175 participants that met inclusion criteria and completed the study, three participants were excluded for failing more than one attention check, two participants were excluded for pasting writing from external sources, and one participant was excluded for mentioning that they have aphantasia (i.e., an inability to visualise mental imagery). These exclusions left us with a final sample of 169 participants (49.11% female; M_{age} = 25.49 (2.66) years). The majority of participants identified as White (64.50%) followed by Black or African American (16.46%), and the majority of participants were employed full time (60.36%). Table S1 in the Supplementary Materials available online presents full demographic information.

Aiming to replicate the results from Study 1 with participants recruited from a different online source, we increased our target N to 175 participants – approximately triple the number of participants necessary to detect a small effect, as indicated by G*Power. Our final sample of 169 participants provided 2028 unique episodic memory and future simulation trials.

Materials

The adapted Autobiographical Interview. As in Study 1, we utilised the automated AI scoring procedure to score the amount of objective detail in the Replication written narratives (Van Genugten & Schacter, in press). We vali- dated this approach on the Replication dataset using 60 past and future events randomly selected from the Replication data. As before, these events were scored both manually and with the automated scoring protocol, and the correlation between these scores was assessed. Internal detail classification was correlated at $r(58) = .78, p < .001$, and external detail scores were correlated at $r(58) = .64, p < .001$, which are again in line with correlations from previous studies (Van Genugten & Schacter, in press). The levels of misclassification in the automated scoring, computed by correlating the manually scored internal detail count with the automated scoring external count, and vice versa, were again not significant in these Replication data ($r(58) = -.10, p = .43$, and $r(58) = -.06, p = .64$, respectively), indicating that this automated scoring system is fit for use in the Replication sample. As in Study 1, we computed the reliability of these scoring methods by normalising the manual and automated scores of the 60 events, then conducting intraclass correlation (ICC) analyses employing a two-way random effects model. For internal details, reliability was good, ICC(2,2) = .78, 95% CI[0.66 - 0.86], and for external details, reliability was moderate, ICC(2,2) = .65, 95% CI[0.47–0.77].

Procedure

The procedure for this Replication was identical to that of Study 1, with one addition. Participants rated how *frequently* they have thought about the event for both *future simulation* trials and *episodic memory* trials, rather than only *future simulation* trials as in Study 1.

Analytic plan

We followed the same analytic plan as described in Study 1, with minor modifications. First, given that we collected ratings of simulation frequency for both *episodic memory* and *future simulation* trials, a three-way interaction between grandiosity, valence, and task predicting frequency was added to analyses. Additionally, in the Replication we found that participants scoring higher in grandiosity rated negative events as more positive and positive events as more negative than those scoring lower in grandiosity ($\beta = -0.01$, 95% CI[$-0.02 - -0.01$], $p < .001$).

This pattern was not present in Study 1. This unexpected influence of grandiosity on the emotional tone of events resulted in a smaller range of event valence among the participants scoring higher in grandiosity in comparison to those scoring lower in grandiosity. Given that this unexpected result was likely to confound our primary analyses, which rely on the interaction between grandiosity and valence, we added the subjective *emotional tone* rating as an additional fixed effect into the model to control for this difference. Due to a software error, one *vividness* rating was not recorded, and thus not included in analyses.

Results

Descriptive statistics

Participants' grandiose narcissism scores (FFNI-SF grandiosity score) ranged from 50 to 178 (M = 112.95, SD = 30.38). Welch's two-sample t-test found that the level of grandiosity in the Replication sample did not significantly differ from that of the Study 1 sample ($t(260.81) = 1.91$, $p > .05$). To check our cue word valence manipulation, we evaluated the influence of cue word valence (positive vs. negative) on participants' ratings of emotional tone of events (i.e., *Overall, the tone of this memory/future event is …* ;1 = extremely negative; 7 = extremely positive). Events cued with positive words had an average emotional tone rating of 5.91 (SD = 1.15) and events cued with negative words were rated an average 2.89 (SD = 1.63) emotional tone. We again used a linear mixed effects model predicting emotional tone from cue word valence with a random effect of participant to confirm that our manipulation of cue word valence indeed predicted ratings of emotional tone ($\beta = 3.02$, 95% CI[2.90–3.14], $p < .001$).

Primary analyses

Full model output is available in Table 3. We replicated the predicted interactions between grandiosity and valence across difficulty ratings ($\beta = -0.01$, 95% CI[−0.01–0.00], p_{fdr} =

.025), vividness ratings ($\beta = 0.01$, 95% CI[0.00–0.01], $p_{fdr} = .025$), frequency ratings ($\beta = 0.01$, 95% CI[0.00–0.02], $p_{fdr} < .001$), and plausibility ratings ($\beta = 0.01$, 95% CI[0.00– 0.02], $p_{fdr} < .001$). As with Study 1, these interactions remained significant (all $ps_{fdr} < .05$) when controlling for potential confounding variables (i.e., self-esteem as measured by the RSES [Rosenberg, 1965], depression symptoms as measured by the depression subscale of the DASS-21 [Lovibond & Lovibond, 1995], anxiety symptoms as measured by the anxiety subscale of the DASS- 21, visual imagery capability as measured by the VVIQ [Marks, 1973], and fantasy proneness as measured by the CEQ [Merckelbach et al., 2001]). These interaction effects all also held when models were run using an ordinal regression approach, except for vividness, which was trending ($p_{fdr} = .08$). We did not replicate the two-way interaction predicting visual perspective ratings ($\beta = -0.00$, 95% CI[−0.01–0.01], $p_{fdr} = .948$). Consistent with findings from Study 1, we found no significant impact of the interaction of grandiosity and valence on objective detail in this replication study (Internal: $\beta = 0.00$, 95% CI[−0.09 - 0.10], $p_{fdr} = .956$; External: $\beta = 0.00$, CI = [−0.09–0.09], $p_{fdr} = .956$). Table S1.6 in the Supplementary Materials available online presents full output of objective detail models. This lack of an interaction of grandiosity and valence on objective detail still held when we used internal and external density as dependent variables to control for verbosity.

Table 1.3 *Replication Study Linear Mixed Effects Model Output for Subjective Rating Analyses*

	Difficulty				Vividness				Visual Perspective				Simulation Frequency				Plausibility			
Predictors	β	95% CI	p	p_{fdr}	β	95% CI	p	p_{fdr}	β	95% CI	p	p_{fdr}	β	95% CI	p	p_{fdr}	β	95% CI	p	p_{fdr}
(Intercept)	3.64	2.87, 4.41	**<.001**	**<.001**	4.13	3.47, 4.79	**<.001**	**<.001**	3.44	2.56, 4.31	**<.001**	**<.001**	1.58	0.90, 2.25	**<.001**	**<.001**	5.17	4.51, 5.84	**<.001**	**<.001**
Grandiosity	0.00	-0.00, 0.01	.176	.294	0.00	-0.01, 0.01	.995	.995	0.00	-0.01, 0.01	.898	.995	0.01	0.00, 0.01	**.002**	**.010**	-0.01	-0.01, -0.00	**.025**	**.064**
Valence (pos)	0.93	0.16, 1.70	**.018**	**.029**	-0.93	-1.57, -0.29	**.004**	**.011**	-0.27	-1.04, 0.50	.491	.491	-0.81	-1.51, -0.11	**.023**	**.029**	-1.45	-2.22, -0.68	**<.001**	**.002**
Task (memory)	-2.37	-3.07, -1.67	**<.001**	**<.001**	1.42	0.83, 2.01	**<.001**	**<.001**	-1.48	-2.20, -0.76	**<.001**	**<.001**	0.71	0.08, 1.33	**.027**	**.027**				
Emotional Tone	-0.14	-0.19, -0.09	**<.001**	**<.001**	0.14	0.09, 0.18	**<.001**	**<.001**	0.04	-0.01, 0.09	.143	.143	0.13	0.08, 0.17	**<.001**	**<.001**	0.19	0.12, 0.26	**<.001**	**<.001**
Grandiosity x Valence	-0.01	-0.01, -0.00	**.018**	**.025**	0.01	0.00, 0.01	**.020**	**.025**	-0.00	-0.01, 0.01	.948	.948	0.01	0.00, 0.02	**<.001**	**<.001**	0.01	0.00, 0.02	**<.001**	**<.001**
Grandiosity x Task	0.01	0.00, 0.02	**<.001**	**.001**	-0.01	-0.01, -0.00	**.029**	**.039**	0.01	0.00, 0.01	**.011**	**.023**	-0.00	-0.01, 0.00	.237	.237				
Valence x Task	0.92	-0.08, 1.91	.070	.281	-0.12	-0.96, 0.72	.771	.911	0.57	-0.45, 1.59	.273	.546	-0.05	-0.93, 0.83	.911	.911				
Grandiosity x Valence x Task	-0.00	-0.01, 0.00	.255	.534	-0.00	-0.01, 0.01	.925	.925	-0.00	-0.01, 0.01	.424	.566	-0.00	-0.01, 0.00	.267	.534				
Random Effects																				
σ^2	2.19				1.56				2.30				1.73				1.71			
τ_{00}	0.92 $_{\text{subjectID}}$				0.72 $_{\text{subjectID}}$				1.45 $_{\text{subjectID}}$				0.65 $_{\text{subjectID}}$				0.52 $_{\text{subjectID}}$			
	0.03 $_{\text{stim}}$				0.01 $_{\text{stim}}$				0.01 $_{\text{stim}}$				0.04 $_{\text{stim}}$				0.09 $_{\text{stim}}$			
ICC	0.30				0.32				0.39				0.29				0.26			
N	12 $_{\text{stim}}$				12 $_{\text{stim}}$				12 $_{\text{stim}}$				12 $_{\text{stim}}$				12 $_{\text{stim}}$			
	169 $_{\text{subjectID}}$				169 $_{\text{subjectID}}$				169 $_{\text{subjectID}}$				169 $_{\text{subjectID}}$				169 $_{\text{subjectID}}$			
Observations	2028				2027				2028				2028				1014			
Marginal R^2 / Conditional R^2	0.087 / 0.364				0.063 / 0.362				0.025 / 0.404				0.088 / 0.349				0.042 / 0.295			

Note. p_{fdr} = p-values following False Discovery Rate multiple comparisons correction. Grandiosity = Grandiosity score from the Five-Factor Narcissism Inventory - Short Form. Valence = positive vs. negative cue word. Task = episodic memory vs. future simulation. Blank cell indicates that element is not applicable.

Exploratory analyses

As in Study 1, there were no significant main or interaction effects when grandiosity was replaced by vulnerability in all subjective rating and objective detail analyses. Full output is available in Tables S1.7 and S1.8 of the Online Supplementary Materials.

The results of the communal vs. agentic cue word exploratory analyses replicated Study 1, with cue word type not significantly interacting with grandiosity and valence to predict any outcomes of interest in the subset of trials cued by “smart,” “stupid,” “kind,” and “mean” (all $ps_{fdr} > .05$; see Table S1.9 in Supplementary Materials for full model output).

Summary

In the Replication Study, as in Study 1, people scoring higher in grandiosity reported greater vividness and ease of retrieving and simulating past and future positive events than negative events, more so than those scoring lower in grandiosity. People scoring higher in grandiosity also reported having thought about positive events more frequently. They also rated future events in which they embodied positive traits as more plausible. In contrast to Study 1, the visual perspective of people scoring higher in grandiosity did not vary based on the valence of the event. Moreover, we found no evidence of three-way interactions, indicating that these effects were the same across both past and future events. As with Study 1, we found no impact of the interaction of grandiosity and valence on internal or external details provided in participants’ written narratives.

General Discussion

In two independent studies, we sought to identify and characterise differences in the episodic memories and future simulations of people scoring high in grandiosity. Despite the well-established clinical intuition that people higher in grandiosity demonstrate a positivity bias in future simulation, these are the first studies to empirically test this prediction. Replicating prior work, we found that people scoring high in grandiosity had consistent, self-bolstering tendencies in episodic memory. Extending prior work, we also show for the first time that these tendencies persist in future simulation. Specifically, people scoring high in grandiosity remember past events and imagine future events in which they embody positive traits with more ease and detail than past and future events in which they embody negative traits. They think about past and future events in which they embody positive traits more frequently than those in which they embody negative traits, and they believe that future events in which they embody positive traits are more plausible than those in which they embody negative traits. These findings were specific to narcissistic grandiosity, as they were not found in exploratory analyses for narcissistic vulnerability. This pattern of self-bolstering tendencies in grandiosity is not mirrored in the amount of objective detail as measured in the written descriptions of remembered and simulated events.

Simulation frequency and plausibility were the strongest findings across both samples. Taken together they suggest one mechanism through which grandiosity may be maintained. Prior work has shown that repeatedly simulating an emotional future event increases the subjective plausibility of that future event (Szpunar & Schacter, 2013). In other words, the more often one thinks about a possible future event, the more likely one is to believe it will occur. Simulating future events in which they display positive traits more often than future events in which they demonstrate negative traits may explain why people scoring higher in grandiosity find those positive events more plausible. Over time, this over-estimation of plausibility could cause grandiose individuals to develop unrealistically positive beliefs about who they will become in the future. Moreover, this might contribute to the persistent feeling of being wronged that is common among those high in grandiosity (e.g., Brunell & Davis, 2016; Macenczak et al., 2021). If one envisions their future as unrealistically positive, reality will likely violate these high expectations and result in feelings of injustice, disappointment, or shame.

Complementing this positive future thinking, self-bolstering tendencies in memory may further contribute to how grandiosity is maintained in the face of real-world evidence of one's faults. For example, if a grandiose person rarely recalls times in which they were stupid or inadequate but frequently recalls times in which they were smart or skilled, they will develop an inaccurate perception of their intellect and abilities. If negative past experiences are not recalled in detail (or are not recalled at all), it may hinder one's ability to learn from past mis- takes, or in the extreme, believe that they occurred.

Although we suggest that these self-bolstering tendencies are maladaptive, they may also be beneficial. For example, if one believes that they have been and will be kinder, smarter, and more interesting than they actually were or will be, they may feel heightened confidence, self-esteem, and satisfaction. This possibility aligns with research that grandiosity confers some benefits, such as increased psychological health (Sedikides et al., 2004), life satisfaction (Kaufman et al., 2020), and resilience (Sękowski et al., 2023), though importantly, these benefits are largely explained by grandiosity's relationship with self-esteem and extraversion (e.g., Sedikides et al., 2004; Kaufman et al., 2020). Overall, it seems most likely that this cognitive style at modest levels confers benefits, whereas at more extreme levels gives way to maladaptive beliefs that may merit clinical intervention, as is the case with many narcissistic features (e.g., Jauk & Kaufman, 2018). To disentangle these effects, future work should aim to examine the extremity of self-bolstering memory and future simulation tendencies in clinical samples with NPD.

Prior examinations of memory differences in narcissism have focused on differentiating between agentic vs. communal memories, reflecting the agency model of narcissism (e.g., Ritchie et al., 2015; for review, Jones, 2018). However, our exploratory analyses did not find evidence that the agency of the cue word significantly influenced differences in episodic memory or future simulation: people scoring high in grandiosity had positive tendencies for both agentic and communal past and future events. This outcome differs from the findings of Jones and colleagues (2017), who found that the positive tendencies only held for agentic words. This discrepancy may be due to Jones et al.'s use of the NPI, a measure that reflects agentic narcissism (Ackerman et al., 2011; Gebauer et al., 2012), in comparison to our use of the grandiosity score of the FFNI-SF, which reflects the broader construct of grandiose narcissism. Alternatively, it may be due to a low sample size hindering our ability to detect an effect, given that these exploratory analyses only include data from four cue words. Albeit preliminary, our findings support the idea that grandiosity extends to communal traits (e.g., Gebauer & Sedikides, 2018) and suggests that differences in episodic memory and future simulation may be more generalised and widespread than previously thought.

It is also worth considering the possibility that these results do not suggest unrealistically positive recall and simulation, but rather reflect true differences in past and likely future experiences. For example, if higher grandiosity participants are truly more skilled and smart, they may have more accessible memories of times when they embodied these traits. This might then be reflected in their responses to particular cue words. If, for example, narcissistic people tend to seek out admiration (e.g., Back et al., 2013), they may have more memories aligning with the cue word admired. However, there is little or conflicting evidence that narcissism is associated with the majority of the cue words in a way that would produce more accurate performance. For example, there were cue words smart and stupid, but narcissism is not associated with intelligence (Zajenkowski et al., 2020). Similarly, narcissism is associated with less prosocial and more antagonistic behaviour (e.g., American Psychiatric Association, 2013; Konrath & Tian, 2018; Weiss et al., 2019), suggesting that if anything, real world experience should drive results in the opposite direction of the present findings for cue words kind and mean. Future studies may benefit from receiving third-party ratings of participant traits, to increase confidence that self-report is more likely reflecting internal biases than real-world experiences.

Beyond the domains of personality and clinical psychology, these findings have important implications for cognitive psychology. By demonstrating a parallel tendency in future simulation to one that has been documented in epi- sodic memory in this population, this work supports the hypothesis that episodic memory and future simulation are subserved by a common constructive retrieval process (the constructive episodic simulation hypothesis; see Schacter & Addis, 2007, 2020). Under this view, future simulation is supported by episodic memory, as details stored in memory are flexibly recombined to con- struct novel future scenarios. The current studies and prior work (Jones & Brunell, 2014; Jones et al., 2017; Marchlewska & Cichocka, 2017) have demonstrated that people higher in grandiosity are prone to retrieve past events through a self-bolstering lens. The extension of this pattern to future simulation in the present work sup- ports this flexible recombination framework. Moreover, when interpreted in light of the self-memory system, these results provide insight into how one's self-concept can influence episodic memory retrieval, and demonstrate that this influence extends to future simulation (Conway, 2005; Schacter et al., 2023). Consistent with our findings, common tendencies between episodic memory and future simulation have been shown in many different psychopathologies, including major depressive disorder, post-traumatic stress disorder, and schizophrenia (e.g., Williams & Dritschel, 1988; Addis, Hach, & Tippett, 2016; Brown et al., 2013; McLeodetal., 2006; see Brunette & Schacter, 2021 for a review of episodic simulation in psychopathology). This is the first extension of work characterising both episodic memory and future thinking to the domain of personality pathology, and thus broadens this domain of research regarding constructive episodic simulation.

Another notable cognitive implication is the dissociation we observed between objective and subjective detail, such that the interaction of grandiosity and valence impacts subjective ratings of detail, ease, plausibility, and frequency of simulation, but not objective detail provided in written narratives. This finding is not entirely surprising, given a growing body of literature suggesting that objective and subjective detail tap into different aspects of an event, as these two types of detail are differentially impacted by task manipulations (Folville et al., 2020) and may be supported by different brain regions (Thakral, Madore, & Schacter, 2020). Further, recent work directly assessed the relationship between subjective vividness and Autobiographical Interview detail counts. Lockrow et al. (2023) found that vividness ratings were not uniquely related to internal detail count as predicted, but also related to external detail count, which the authors suggest may reflect nonspecific associations with overall verbal output. Accordingly, the demonstrated dissociation between subjective and objective detail in the present work may reflect real discrepancies between subjective phenomenological ratings and objective detail measures. It is also possible that this discrepancy between objective and subjective detail reflects a reporting bias, such that people higher in grandiosity are more likely to endorse more detail and ease in positive events in order to self-enhance, without a corresponding difference in their actual subjective experience. Future work should use measures of memory and simulation quality that do not require self-report to disentangle these possibilities. Finally, the present work also speaks to some of the functions of episodic memory and future simulation in daily life, contributing to one's sense of self and aiding in emotion regulation (cf., Jing et al., 2016).

Limitations

Although a strength of the present study's design is the larger number of cue words than prior work, it is possible that these results are specific to the twelve cue words chosen and not positive and negative events more broadly. Moreover, the sample size in the present work may have prevented us from detecting three-way inter- actions. Future work should aim to replicate these findings with different cue words or study designs and larger samples to bolster confidence in the generalizability of these findings. We used an automated AI scoring method to assess for objective detail in the present work, and it is possible that this automation obfuscated findings that would have been present with manual scoring. It is also important to consider that there are multiple models of narcissism, including a three-factor model conceptualising narcissism into antagonistic, agentic, and neurotic aspects (Crowe et al., 2019). Although we selected a two-factor approach given our specific interest in the impact of grandiosity on future thinking, examining alternative models could provide additional specificity. Moreover, the present work, while suggestive, cannot directly speak to whether episodic memory and future simulation may be a causal mechanism to maintain a bolstered sense of self among grandiose individuals. Future work should aim to evaluate these cognitive tendencies longitudinally and assess how they change in response to narcissistic injury to gain more insight into possible causality. Further, replicating these findings under more naturalistic conditions, for example, using ecological momentary assessment to examine the type of events that grandiose individuals are naturally remembering and imagining, and whether this process bolsters self-esteem in their daily lives, would be of value. Lastly, our online samples were recruited to reflect a wide range of grandiosity, and thus caution should be made around any clinical interpretations related to NPD, which may or may not be represented in the present sample.

Conclusion

Overall, this study provides compelling evidence that grandiosity is characterised by self-bolstering cognitive tendencies in both episodic memory and future simulation. We find that these self-bolstering tendencies persist across several different subjective evaluations of past and future events and suggest that grandiosity may be maintained through repeated simulation of positive events, which therefore seem more plausible. This study lays a foundation for future work examining memory and future thinking in relation to narcissism, demonstrating that grandiose individuals have a propensity for thinking about themselves in the past and future in a positive light.

Chapter 3: Paper 2

Neural correlates of subjective spatial detail in episodic retrieval and future thinking

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Abstract

Remembered past events are typically rated higher in subjective spatio-contextual detail than imagined future events. However, there have been mixed findings of corresponding heightened neural activity during episodic memory retrieval compared to episodic future thinking. Here, we sought to characterize the neural underpinnings of this behavioral difference. Healthy young adult participants (N=26) underwent an fMRI scan, during which they remembered past events and imagined future events in their lives. Following each trial, participants were prompted to rate the subjective clarity of the location and clarity of the arrangement of people in the event. We found significantly greater activity during memory than future thinking in the precuneus, occipital cortex, mid-cingulate cortex, and dorsolateral prefrontal cortex. Using a median split analysis, we identified that the precuneus, anterior cingulate, dorsolateral prefrontal cortex, and medial prefrontal cortex were more active during memories with high subjective location detail than low location detail. High clarity of arrangement of people during memory was associated with greater activity in the precuneus, lingual gyrus, early visual cortex, and dorsolateral prefrontal cortex compared with low clarity of arrangement of people during memory. In contrast, no regions showed greater activity associated with high location or people detail during future trials. Results from a parametric modulation analysis converged with these median-split findings, and demonstrated that, across memory and future thinking trials, subjective spatial detail about both people and locations was associated with activity in the precuneus. The implications of these results for the interplay of oculomotor systems and a core episodic network are discussed.

Keywords: episodic retrieval, episodic future thinking, fMRI, spatiocontexual detail

Introduction

Research aiming to understand how people remember events from the past, or episodic retrieval, has emphasized the parallels with episodic future thinking. This body of work has provided valuable insight, as stated previously, that episodic memory binds component parts of an event, which may later be retrieved or flexibly recombined to construct a representation of a past or imagined future event (Schacter & Addis, 2007, 2020). These processes are known to recruit a common "core network" of brain regions (Benoit & Schacter, 2015; see Schacter et al., 2012 for review).

While there are several similarities between episodic retrieval and future thinking described above (Schacter & Addis, 2007, 2020), it is also useful to consider differences between these two processes. One such difference is that participants report greater subjective spatial detail in episodic memories compared to episodic future thoughts (D'Argembeau & van der Linden, 2004, 2006; Johnson et al., 1988; Szpunar & McDermott, 2008). This finding is notable because spatial contextual detail, or rich spatial information in an event, is thought to serve as a scaffold for the construction of an event (for review, see Robin, 2018). When participants are asked to imagine a specific event but are not provided with a location cue, they will often spontaneously generate one (Robin et al., 2016). Participants tend to spontaneously recall spatial details before retrieving any other information about a past episode, and those with a greater tendency to recall these spatial details first also have a faster event construction reaction time (Hebscher et al., 2018). Specifically boosting spatial contextual processing enhances the generation of episodic details when recalling past events and leads to a preference for generating perceptual details for both past and future events (Sheldon et al., 2019). Rubin et al. (2019) drew upon the importance of a spatial scaffold during episodic retrieval, finding that the clarity of location information (including *where* event contents, like people or objects. were located) contributes more to overall vividness and degree of reliving than the clarity of the scene's contents themselves. Similar effects were found during episodic future thinking: spatial detail, and not content-specific detail, uniquely tracked subjective judgments of detail and vividness (Hallford et al., 2023). Taken together, these findings demonstrate that both episodic retrieval and future thinking utilize, and perhaps even prioritize, spatial context as part of the constructive process.

This behavioral difference is particularly interesting, given the dearth of neuroimaging results paralleling the greater spatial detail during episodic retrieval than future thinking. Only a few studies have reported greater activity during episodic retrieval than future thinking. Addis et al. (2009) used spatiotemporal partial least squares to identify task-dependent subsystems within the core network. They identified a subsystem unique to episodic retrieval that included the right hippocampus, paraphippocampal gyrus, retrosplenial cortex, and swaths of visual cortex including BA17 and BA18. They interpret this finding as a demonstration of recapitulation: that the rich sensorial and contextual detail becomes reactivated while retrieving a past event in regions that originally processed this information while retrieving a past event (e.g. Johnson et al., 2008; Kahn et al., 2004). Weiler et al. (2010) employed a construction-elaboration procedure, during which episodic retrieval is divided into two stages: a construction phase, during the strategic search for a specific memory or generation of a novel future event based on retrieval goals, and an elaboration phase, when the event is reexperienced or generated in detail (Addis et al., 2007; Conway et al., 2001). They found increased activity for episodic retrieval > future thinking during the elaboration phase in the precuneus, the inferior and superior occipital gyri, and inferior parietal lobule, which they speculate could in part reflect the phenomenological richness of episodic retrieval. Others have found greater activity in the posterior cingulate cortex, parahippocampal cortex, and the superior occipital gyrus for both retrieval and future simulations of events in familiar contexts compared with during future events in unfamiliar settings, suggesting that familiar settings contain greater contextual detail, thus driving activity in these regions (Szpunar et al., 2009). Gilmore et al. (2016) interrogated whether the scarcity of effects that are greater for retrieval than future thinking could be due to the use of whole-brain contrasts on effects that could potentially be better characterized using an ROI analysis. Drawing upon work identifying the retrosplenial cortex and parahippocampal cortex as being central to spatiocontextual processing (Aminoff et al., 2007; Bar et al., 2008; Bar & Aminoff, 2003), they used these regions as ROIs to compare activity during episodic retrieval and episodic future thinking. Within these ROIs, they identified greater activity during episodic retrieval than episodic future thinking and interpreted this increased activity as tracking the heightened spatiocontexual detail in episodic retrieval (see McDermott & Gilmore, 2015 for review). While a substantial body of evidence has aimed to assess this disconnect between the greater spatial detail in episodic retrieval and the inconsistent neural results demonstrating a similar effect, no studies to date have directly incorporated behavioral measures of subjective spatial detail. Therefore, the first aim of the present study is to directly assess the neural correlates of these behavioral ratings across episodic retrieval and future simulation.

Parsing category detail in the core network

Remembered past and imagined future events include substantial detail beyond spatial information: participants must integrate information about people and objects into a specific location and mentally play that event out in time. The degree of detail associated with these individual features is potentially meaningful as each of these details are flexibly recombined into a coherent event. Szpunar, St. Jacques, et al. (2014) used a repetition suppression paradigm, which leverages the phenomenon that neurons show decreased responsiveness after repeated presentation of stimuli to which they are attuned; in fMRI studies, this effect is evident as a greater response to novel than repeated stimuli (Grill-Spector et al., 2006; Schacter et al., 2007). Szpunar, St. Jacques, et al. had participants repeatedly simulate future events while varying the types of content that repeated (locations, people, and objects), thus generating a unique neural signature associated with these different types of content in episodic future thinking. They found that simulating details about people was associated with repetition suppression in the medial prefrontal cortex, simulation of objects was associated with repetition suppression in the left inferior prefrontal cortex and left premotor cortex, and location details were linked with the posterior cingulate, angular gyrus, and parahippocampal cortex. Szpunar, St. Jacques, et al. (2014) also identified repetition enhancement effects for both objects and people that overlapped at the border of the cuneus/precuneus. These results demonstrate that the unique types of content that compose an episodic future thought are supported by activity in both common and distinct regions. In sum, these findings demonstrate candidate common and distinct brain regions for processing different types of episodic content. Motivated by this work, we aim to compare the regions tracking ratings of spatial information about locations and ratings of the spatial arrangement of people in a given event to understand how these various details are recombined into a coherent event.

Parsing subjective detail in the core network

Prior work has incorporated ratings of subjective and objective detail into the analysis of episodic retrieval and future thinking with fruitful results. Subjective detail refers to participants' ratings of the phenomenological experience of an event (e.g. vividness), whereas objective detail refers to the quantifiable amount of episodic detail produced while retrieving or simulating an event (e.g., the amount of internal detail scored during the Autobiographical Interview [Levine et al., 2002], or memory precision, a continuous measure of how closely an internal representation matches what was initially presented [Brady et al., 2013]). Retrieval success, memory precision, and vividness have been dissociated during episodic retrieval: retrieval success was associated with hippocampal activity, precision tracked with the angular gyrus, and vividness tracked the precuneus (Richter et al., 2016). Thakral, Madore, and Schacter (2020) investigated whether, during episodic future thinking, regions within the core network differentially track ratings of subjective vividness and objective detail, as assessed by the number of internal details in an event. This analysis identified regions, including the hippocampus, that were sensitive to subjective vividness ratings, while other regions including the lateral parietal cortex were sensitive to objective detail.

More broadly, the subjective experience of remembering is thought to be supported by a posterior medial part of the core network, including the precuneus and hippocampus as outlined above, in addition to parahippocampal cortex, retrosplenial cortex, left lateral parietal cortex, posterior cingulate, and medial prefrontal cortex (Simons et al. 2022). Activity in these regions has been interpreted as integrating multimodal event features into a coherent and vivid experience of an event (Addis et al., 2007; Ritchey & Cooper, 2020; Rugg & Vilberg, 2013). According to a detailed review by Simons et al. (2022), the hippocampus is thought to reactivate aspects of an event in an allocentric framework, the lateral parietal cortex is thought to integrate the many features of an event into an egocentric representation, while more medial parietal regions, including the precuneus, bring to awareness a detailed, subjectively multifaceted egocentric representation. Moreover, these posterior medial regions are functionally connected with each other at rest (Andrews-Hanna et al., 2010) and connectivity among these regions during episodic retrieval supports successful recollection (King et al., 2015) and recognition (Geib et al., 2017). Cooper and Ritchey (2019) found that objective measures of spatial memory precision tracked connectivity in posterior medial regions, including the parahippocampal cortex, retrosplenial complex, posterior cingulate, precuneus, and angular gyrus. In addition to emphasizing the unique role in each of these regions to give rise to the spatiocontextual detail of episodic retrieval, this line of work emphasizes the benefit to understanding how posterior-medial network connectivity supports memory performance, though this has been largely unexplored in future thinking. Motivated by this work, we aim to characterize the network dynamics of posterior medial regions during episodic retrieval and future thinking in the present study.

Study Aims

This project aims to provide novel insight into the functions of regions within the posterior medial portion of the core network with respect to their role in supporting different kinds of episodic details during memory retrieval and future thinking. First, we probed which regions track the behavioral effect of greater subjective spatial detail during episodic retrieval than future simulation. Candidate regions include parahippocampal cortex, retrosplenial complex, angular gyrus, precuneus, or posterior cingulate cortex.

Second, we draw upon prior work demonstrating that different contents of an event – locations, people, or objects – modulate distinct and common regions during episodic future thinking (Szpunar, St. Jacques, et al., 2014). The present study allows us to test within the same individuals how these content-level effects are modulated by task, since we also incorporate an episodic retrieval condition in addition to an episodic future thinking condition. Given the known behavioral difference in spatiocontexual detail for episodic retrieval compared to future simulation, we expected that these content-level effects would be stronger during memory retrieval than future thinking.

Finally, this project allows us to assess network dynamics that occur in these posterior medial regions driven by task. We predicted that the ROI-to-ROI connectivity within the posterior medial network would be greater during episodic retrieval than future thinking, particularly in the retrosplenial complex and parahippocampal cortex, paralleling the difference in behavioral ratings between these two tasks.

Methods

Participants

Thirty right-handed native English-speaking participants with normal or corrected-to-normal vision were recruited from the Harvard community and the Boston area, who all reported no history of psychiatric or neurological disorder. Written, informed consent was provided by all participants prior to participation as approved by the Harvard University Institutional Review Board. Four participants were excluded due to excessive motion, defined as having maximal absolute motion > 3mm or more than five individual movements > 0.5mm in any functional run of the main, episodic task (see Benoit et al., 2019). We thus included data from 26 participants (14 F; mean age = 20.5, range = 18-27).

Stimuli and Tasks

Session 1: Stimuli Collection

Participants were first asked to recall 150 memories from their personal past, paralleling prior work using paradigms involving the recombination of episodic details (Addis et al., 2009; McLelland et al., 2015; Thakral, Madore, Addis, & Schacter, 2020). Each event was required to be specific in place and time, to last between a few minutes to a few hours, to be from within the past 5 years, and to be an event that the participant had personally experienced. Participants were also instructed that each memory should be unique with respect to the location where it occurred, and the person (apart from themselves) of primary importance. They were told that they could use their cell phone, social media, and a provided list of event cues to facilitate retrieval.

For each memory, participants provided a brief description of the event to ensure that each memory was specific in time and place. They then indicated the approximate year at which that event occurred, the *person* of primary importance involved in that event, and the *location* where the event occurred. The person detail was specified using the first and last name of that individual, and the location had to be specified using a short (less than 5 word) location label that would allow them to instantaneously imagine the exact location of the memory. Participants were instructed to not include the names of people in their location labels.

Participants provided two ratings for each memory: the clarity of the location, and the clarity of arrangement of people. For the clarity of the location, participants were asked to judge the clarity of their memory for the location where the event takes place, from 1 (not at all clear) to 5 (very clear). For the clarity of the arrangement of people, participants were asked to judge the clarity for the relative spatial arrangement of people in this event, from 1 (not at all clear) to 5 (very clear). Critically, these Likert items were used by D'Argembeau & van der Linden (2006) as part of a metric of spatial context in episodic retrieval and future simulation.

Prior to Session 2, 54 of these events were randomly selected to be Remember trials, 54 were randomly selected to be Future trials, and 24 were randomly selected for use in the Imagery Localizer task. Among the Future trials, person and location details were randomly combined to create 54 person/place pairings that were different from the original events provided. Four additional events served as practice.

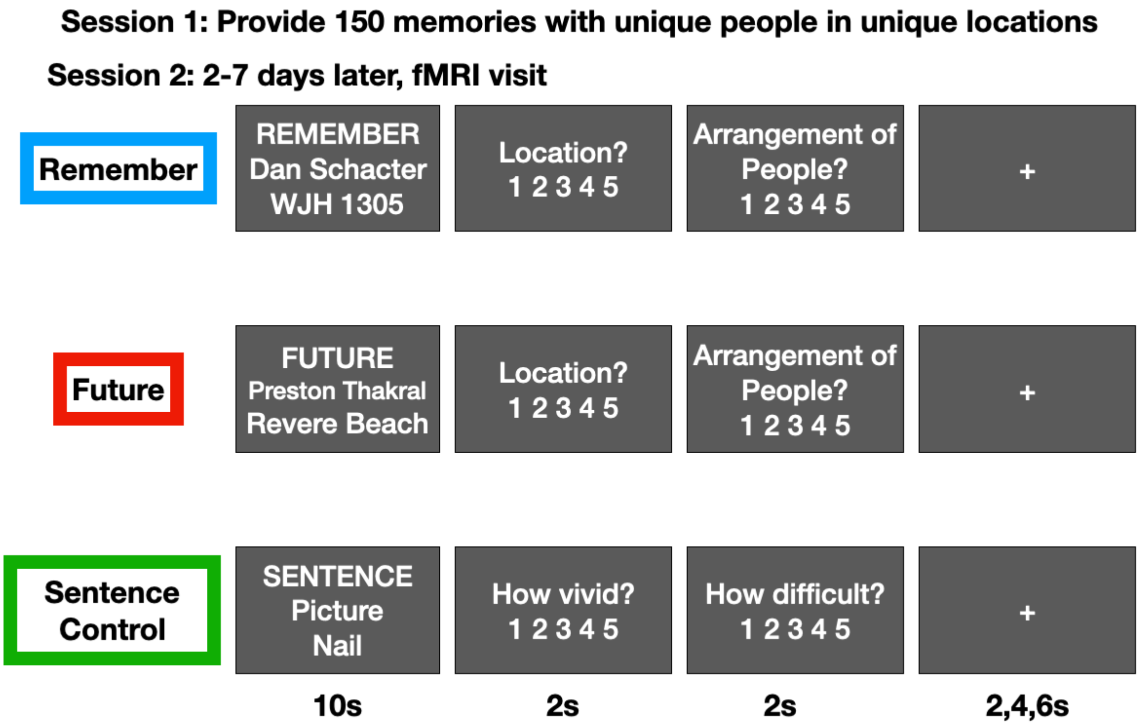
Session 2: Experimental Phase

Between 2-7 days following Session 1 (median delay: 4.5 days), participants returned for an fMRI scan visit.

The Episodic Task phase was composed of Remember, Future, and Sentence tasks, which alternated pseudorandomly from trial to trial. For each trial, participants were presented with the task cue at the top of the screen. On Remember and Future trials, the name of a *person* and the name of a *location* they provided during Session 1 appeared below the task cue. For Remember trials, participants were instructed to remember the event that they provided at Session 1 containing the corresponding person and location details presented on screen in as much detail as possible. During Future trials, participants were instructed to imagine interacting with the given person in the given location in the next few years in as much detail as possible, noting that these events should be novel, specific, and be experienced from a first-person perspective. After each Remember and Future trial, participants were prompted to rate the clarity of the location and the clarity of the arrangement of people using the same scale as they had in Session 1. On Sentence trials, participants were presented with the task cue and two concrete words. They were instructed to first generate a word related to both words on the screen, then come up with a sentence ranking those words according to the size of the objects to which they refer, then generate the definition of each object, as if from a dictionary, until the trial is over. After each Sentence trial, participants were asked to rate how vivid the items were in their minds eye (1: not at all vivid, 5: very vivid) and how difficult the task was on a 5-point scale (1: easy, 5: difficult). This Sentence condition was chosen as a control task because it shares generative processes with the Remember and Future tasks, including search, retrieval, and integration of details related to an object cue (Benoit et al., 2014; Thakral, Madore, Addis, & Schacter, 2020). For each trial of the three tasks, the task cue was on screen for 10s, followed by the two questions which were displayed for 2s each. Trials were separated by a fixation cross on screen for a jittered interstimulus interval of 2, 4, or 6s. After practicing these tasks, participants completed 6 Episodic Task runs, each containing 9 Remember trials, 9 Future trials, and 6 Sentence Trials. Each scan of the episodic task lasted 7 minutes and 28 seconds. Due to a technical issue, one participant only completed 5 runs of this task.

Participants completed their time in the scanner with a rest scan and an anatomical scan. During the post-scan session, participants were re-presented with one Remember cue and one Future cue from each of the Episodic Task runs. They were asked to speak aloud in as much detail as possible about what they thought about in the scanner to ensure that they had been compliant to the task.

Figure 2.1 Episodic task design



Note. Episodic task design. Participants provided 150 memories including unique people in unique locations. Within 2-7 days following the first session, they returned for an fMRI study visit. During the fMRI scan, participants remembered past events, provided with people and location details from the same event provided during Session 1, or imagined future events, provided with person and location details from different events provided during Session 1. Following these tasks, participants were prompted to rate the clarity of the location and the clarity of the arrangement of people in that event on a Likert scale from 1 (not at all vivid) to 5 (very vivid). A sentence control task also occurred pseudorandomly during the scan, during which they generated an object related to two on the screen, put them in a sentence comparing their size, then generating dictionary definitions for each.

fMRI Acquisition

All images were acquired on a 3T Siemens MAGNETOM Prisma scanner, using a 32-channel head coil. Foam padding was applied to stabilize each participant's head, and foam earplugs were provided to reduce scanner noise. Functional images for the task scans were acquired using a multiband echo-planar imaging sequence (University of Minnesota C2P sequence: TR = 2s, TE = 30ms, matrix size of 124x124, 87 slices [MB factor = 3], 1.7 mm^3 resolution) (Feinberg et al., 2010; Moeller et al., 2010; Xu et al., 2013). The Episodic Task collected 224 volumes of this sequence. Slices were auto-aligned to an angle 20 degrees toward coronal from anterior-posterior commissure alignment. Lastly, a high-resolution T1 structural image was obtained for each participant (TR =2530.0 ms, TI = 1100 ms, flip angle = 7.0 degrees, FOV = 256 mm with 1mm isotropic voxels).

An Apple MacBook computer (Apple) running PsychoPy software (Peirce et al., 2019) displayed visual stimuli to the participants on an InFocus IN5542 projector. Responses were recorded from a 5-key button box on each participant's right hand.

Data Preprocessing

Results included in this manuscript come from preprocessing performed using *fMRIPrep* 22.0.0 (Esteban, Markiewicz, et al. (2018); Esteban, Blair, et al. (2018); RRID:SCR_016216), which is based on *Nipype* 1.8.3 (K. Gorgolewski et al. (2011); K. J. Gorgolewski et al. (2018); RRID:SCR_002502).

Anatomical data preprocessing

The T1-weighted (T1w) image was corrected for intensity non-uniformity (INU) with N4BiasFieldCorrection (Tustison et al. 2010), distributed with ANTs 2.3.3 (Avants et al. 2008, RRID:SCR_004757), and used as T1w-reference throughout the workflow. The T1w-reference was then skull-stripped with a *Nipype* implementation of the antsBrainExtraction.sh workflow (from ANTs), using OASIS30ANTs as target template. Brain tissue segmentation of cerebrospinal fluid (CSF), white-matter (WM) and gray-matter (GM) was performed on the brain-extracted T1w using fast (FSL 6.0.5.1:57b01774, RRID:SCR_002823, Zhang, Brady, and Smith 2001). Brain surfaces were reconstructed using recon-all (FreeSurfer 7.2.0, RRID:SCR_001847, Dale, Fischl, and Sereno 1999), and the brain mask estimated previously was refined with a custom variation of the method to reconcile ANTs-derived and FreeSurfer-derived segmentations of the cortical gray-matter of Mindboggle (RRID:SCR_002438, Klein et al. 2017). Volume-based spatial normalization to two standard spaces (MNI152NLin2009cAsym, MNI152NLin6Asym) was performed through nonlinear registration with antsRegistration (ANTs 2.3.3), using brain-extracted versions of both T1w reference and the T1w template. The following templates were selected for spatial normalization: *ICBM 152 Nonlinear Asymmetrical template version 2009c* [Fonov et al. (2009), RRID:SCR_008796; TemplateFlow ID: MNI152NLin2009cAsym], *FSL's MNI ICBM 152 non-linear 6th Generation Asymmetric Average Brain Stereotaxic Registration Model* [Evans et al. (2012), RRID:SCR_002823; TemplateFlow ID: MNI152NLin6Asym].

Functional data preprocessing

For each BOLD run, the following preprocessing was performed. First, a reference volume and its skull-stripped version were generated using a custom methodology of *fMRIPrep*. Head-motion parameters with respect to the BOLD reference (transformation matrices, and six corresponding rotation and translation parameters) are estimated before any spatiotemporal filtering using mcflirt (FSL 6.0.5.1:57b01774, Jenkinson et al. 2002). BOLD runs were slice-time corrected to 0.955s (0.5 of slice acquisition range 0s-1.91s) using 3dTshift from AFNI (Cox and Hyde 1997, RRID:SCR_005927). The BOLD time-series (including slice-timing correction when applied) were resampled onto their original, native space by applying the transforms to correct for head-motion. These resampled BOLD time-series will be referred to as *preprocessed BOLD in original space*, or just *preprocessed BOLD*. The BOLD reference was then co-registered to the T1w reference using bbregister (FreeSurfer) which implements boundary-based registration (Greve and Fischl 2009). Co-registration was configured with six degrees of freedom. Several confounding time-series were calculated based on the *preprocessed BOLD*: framewise displacement (FD), DVARS and three region-wise global signals. FD was computed using two formulations following Power (absolute sum of relative motions, Power et al. (2014)) and Jenkinson (relative root mean square displacement between affines, Jenkinson et al. (2002)). FD and DVARS are calculated for each functional run, both using their implementations in *Nipype* (following the definitions by Power et al. 2014). The three global signals are extracted within the CSF, the WM, and the whole-brain masks. Additionally, a set of physiological regressors were extracted to allow for component-based noise correction (*CompCor*, Behzadi et al. 2007). Principal components are estimated after high-pass filtering the *preprocessed BOLD* time-series (using a discrete cosine filter with 128s cut-off) for the two *CompCor* variants: temporal (tCompCor) and anatomical (aCompCor). tCompCor components are then calculated from the top 2% variable voxels within the brain mask. For aCompCor, three probabilistic masks (CSF, WM and combined CSF+WM) are generated in anatomical space. The implementation differs from that of Behzadi et al. in that instead of eroding the masks by 2 pixels on BOLD space, a mask of pixels that likely contain a volume fraction of GM is subtracted from the aCompCor masks. This mask is obtained by dilating a GM mask extracted from the FreeSurfer's *aseg* segmentation, and it ensures components are not extracted from voxels containing a minimal fraction of GM. Finally, these masks are resampled into BOLD space and binarized by thresholding at 0.99 (as in the original implementation). Components are also calculated separately within the WM and CSF masks. For each CompCor decomposition, the *k* components with the largest singular values are retained, such that the retained components' time series are sufficient to explain 50 percent of variance across the nuisance mask (CSF, WM, combined, or temporal). The remaining components are dropped from consideration. The head-motion estimates calculated in the correction step were also placed within the corresponding confounds file. The confound time series derived from head motion estimates and global signals were expanded with the inclusion of temporal derivatives and quadratic terms for each (Satterthwaite et al. 2013). Frames that exceeded a threshold of 0.5 mm FD or 1.5 standardized DVARS were annotated as motion outliers. Additional nuisance timeseries are calculated by means of principal components analysis of the signal found within a thin band (*crown*) of voxels around the edge of the brain, as proposed by (Patriat, Reynolds, and Birn 2017). The BOLD time-series were resampled into standard space, generating a *preprocessed BOLD run in MNI152NLin2009cAsym space*. First, a reference volume and its skull-stripped version were generated using a custom methodology of *fMRIPrep*. Automatic removal of motion artifacts using independent component analysis (ICA-AROMA, Pruim et al. 2015) was performed on the *preprocessed BOLD on MNI space* time-series after removal of non-steady state volumes and spatial smoothing with an isotropic, Gaussian kernel of 6mm FWHM (full-width half-maximum). Corresponding "non-aggresively" denoised runs were produced after such smoothing. Additionally, the "aggressive" noise-regressors were collected and placed in the corresponding confounds file. All resamplings can be performed with *a single interpolation step* by composing all the pertinent transformations (i.e. head-motion transform matrices, susceptibility distortion correction when available, and coregistrations to anatomical and output spaces). Gridded (volumetric) resamplings were performed using antsApplyTransforms (ANTs), configured with Lanczos interpolation to minimize the smoothing effects of other kernels (Lanczos 1964). Non-gridded (surface) resamplings were performed using mri_vol2surf (FreeSurfer).

Many internal operations of *fMRIPrep* use *Nilearn* 0.9.1 (Abraham et al. 2014, RRID:SCR_001362), mostly within the functional processing workflow. For more details of the pipeline, see the section corresponding to workflows in *fMRIPrep*'s documentation.

Data were then smoothed to a 4mm full-width half-maximum Gaussian kernel using Statistical Parametric Mapping (SPM12; Wellcome Department of Cognitive Neurology, London, UK).

fMRI Analysis

All analyses were conducted using a general linear model in Statistical Parametric Mapping (SPM12; Wellcome Department of Cognitive Neurology, London, UK). Contrasts of interest were specified at the first level, then carried forward to the second level (random effects) analysis. In all models, an AR(1) model estimated and corrected for non-sphericity of the error covariance (Friston et al., 2002). Subsequent analyses were conducted in MATLAB, R (version 4.3.1) and RStudio (version 1.3.1073).

At the first level, events in the Episodic Task were modeled using a delta function at event onsets convolved with the canonical hemodynamic response function. Events of interest included Remember trials, Future trials, and Sentence trials, while events of non-interest included the Rating period, Error trials (trials during which participants provided no response within the 2s response window), and 13 motion parameters (representing the first six aCompCor components, framewise displacement, and six translational and rotational motion parameters).

To assess the impact of subjective behavioral ratings on BOLD activation, two first-level models were created to identify trials corresponding to the high and low location rating and the high and low people ratings, respectively. To separate these trials into high- and low-rating bins, the median of each rating (location & people) was calculated on an individual participant basis. Ratings greater than or equal to the median were classified as "high," and ratings less than the median were classified as low. Trials were downsampled to ensure that there were an equal number of trials in each bin (Remember/High, Remember/Low, Future/High, and Future/Low). Four participants had fewer than 5 trials per bin using this approach and were thus excluded from this median split analysis. The remaining 21 participants had a mean of 11.73 (4.83) location trials and 12.32 (5.01) people trials.

The participant-specific parameter estimates from this median-split analysis were the mean of a 5mm radius spherical ROI drawn around each peak voxel in a contrast. These estimates were then brought forward into a linear mixed effects model implemented with the *lmer* function in the *lmerTest* package in R (Kuznetsova et al., 2017). These models included fixed effects of task (Memory/Future) and rating (High/Low), and a random effect of participant. For each ROI, we ran one model on the location rating data, and a second model on the people rating data. An FDR correction was applied to all model output, and post-hoc pairwise comparisons on significant model effects were implemented with the *lsmeans* package in R, employing a Tukey HSD adjustment (Lenth, 2016).

We conducted a series of parametric modulation analyses on the data from the Episodic Task to identify regions sensitive to the clarity ratings of the two content types (*location* and *people*). Specifically, we ran one first-level model in which the Remember and Future trials had a parametric modulator of the location clarity rating provided on that given trial, and a second parametric modulator to control for the arrangement of people clarity rating. We then ran the reverse model, in which the clarity of arrangement of people rating was the first parametric modulator, to assess activity specific to the arrangement of people rating, controlling for the clarity of the location. All rating scales were modeled linearly.

For the median split and parametric modulation analyses, data across the six runs were concatenated, and the covariates in the parametric modulation analyses were mean-centered according to SPM algorithms (Mumford et al., 2015; for similar procedures, see Madore, Szpunar, et al., 2016; Thakral, Madore, & Schacter, 2020). An individual voxel threshold of $p < 0.005$, $k = 105$ was employed to correct to a whole-brain $p < .05$ (Slotnick et al., 2003; Slotnick et al., 2017). Given that this threshold is based on Monte Carlo simulations using similar data with the same scanning sequence (Thakral, Madore, & Schacter, 2020), it is a reasonable value to use while cluster corrections are being calculated on the present data.

Background connectivity analyses were conducted using the ROI-to-ROI connectivity feature in CONN Toolbox (Whitfield-Gabrieli & Nieto-Castanon, 2012). ROIs for this analysis were selected from probabilistic anatomical and functional atlases used in previous work parsing the posterior-medial network. Medial temporal ROIs (accessed from https://neurovault.org/collections/3731/; Ritchey et al., 2015) included the anterior hippocampus (aHipp; composed of the hippocampal head), posterior hippocampus (pHipp; composed of the body and tail), parahippocampal cortex (PHC), and perirhinal cortex (PRC). Cortical ROIs (accessed from https://github.com/memobc/paper-camcan-pmn/tree/master/rois; Cooper et al., 2021) included the anterior and posterior angular gyrus (aAG and pAG, respectively), medial prefrontal cortex (MPFC), posterior cingulate (PCC), precuneus (PCU), and retrosplenial cortex (RSC). Unilateral ROIs were flipped and summed such that each ROI was bilateral and resampled to 1.7mm voxels. In addition to the effects of interest described above, these models also contained regressors of the clarity of location and clarity of arrangement of people ratings to ensure that all results were not tied to task activations or behavior, but rather to intrinsic connectivity modulating these networks. Correlation matrices for each participant were generated for both Memory and Future tasks by calculating a Pearson's correlation between the mean time series for each ROI-to-ROI pair. Each subject's correlation matrix was thresholded at 0.25 and FDR-corrected for multiple comparisons.

Results

Behavioral Results

We conducted a behavioral analysis to assess whether, within each rating question (clarity of location, clarity of arrangement of people), we could replicate prior findings of greater subjective contextual detail for Remember trials than Future trials. Indeed, using Welch's two sample t-tests, we found a significant effect for the clarity of the location ratings, $t(2563.9) = -8.23$, $p = 3.02e-16$, as the clarity of the location ratings on Remember trials ($M = 4.10$, $SD = 0.91$) were significantly greater than the clarity of location ratings on Future trials ($M = 3.79$, $SD = 1.01$). There was a similar effect for the clarity of arrangement of people ratings, $t(2605.6) = -17.48$, $p < 2.2e-16$, as the clarity of arrangement of people ratings on Remember trials ($M = 3.52$, $SD = 1.24$) were significantly greater than the clarity of arrangement of people ratings during Future trials ($M = 2.70$, $SD = 1.16$). These findings indicate that, subjectively, spatial contextual details in Remembered events were clearer than those in Future events.

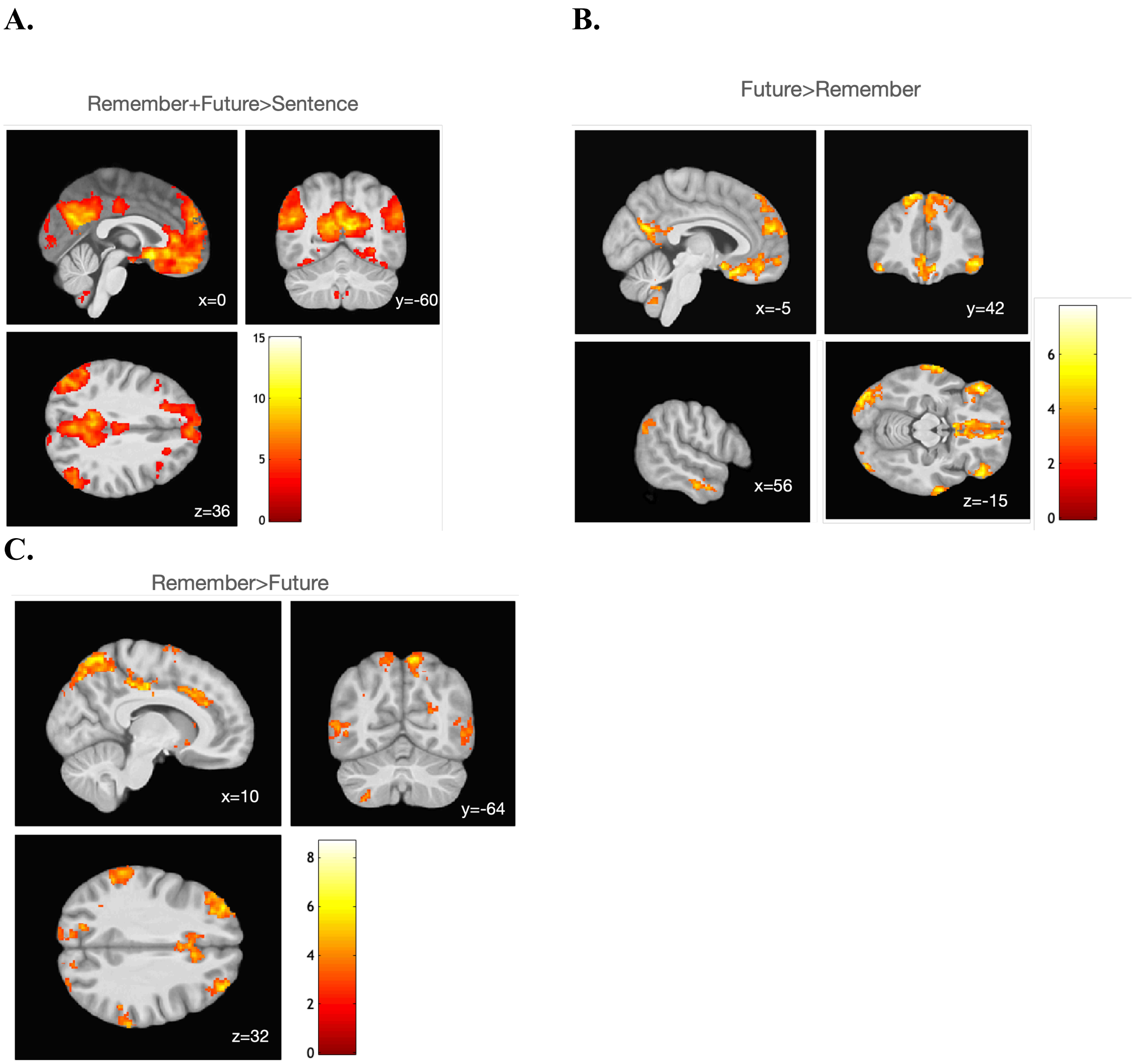
We next assessed whether the two behavioral ratings were correlated with each other on an individual-participant basis. Across all participants, there was a moderate correlation between the clarity of location and clarity of arrangement of people ratings, M (SD) of Spearman correlation r = .40 (.13). For all participants except for one, this correlation was significantly greater than 0.

fMRI Results

We first replicated the standard effect of core network activity in these data that has been reported numerous times (for review, see Benoit & Schacter, 2015) by contrasting activity for the two episodic conditions (Memory + Future) > the non-episodic control (Sentence). We found robust activity in every region of the core network, including lateral parietal cortex, lateral temporal cortex, medial prefrontal cortex, and medial temporal lobes, including the hippocampus (Figure 2.2a; Table S2.1). We also replicated prior work demonstrating greater activity for Future > Memory in the frontal pole and posterior cingulate (Addis et al., 2007; Addis et al., 2009; Addis & Schacter, 2008) (Figure 2.2b; Table S2.2). Notably, we do find regions sensitive to the Memory > Future contrast at the whole-brain level in the precuneus, midcingulate cortex, posterior cingulate, early visual, and lateral occipital cortex (Figure 2.2c; Table S2.2).

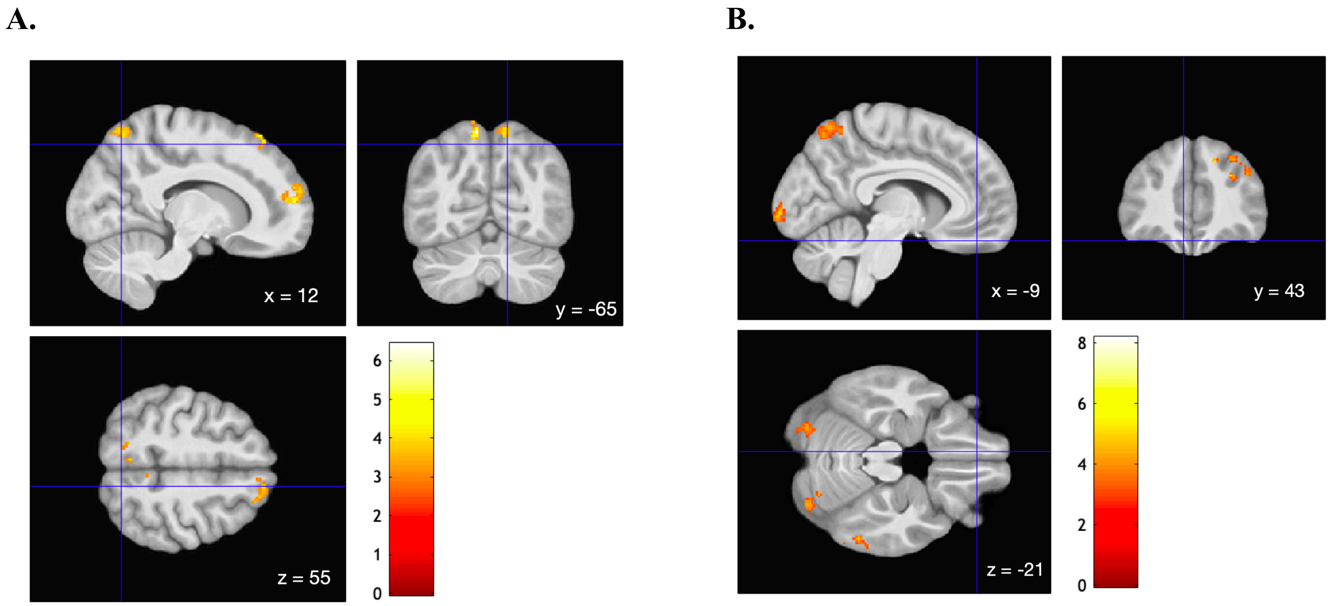
We next turned to the median split analysis to characterize regions tracking High > Low clarity across ratings (Location/People) and tasks (Memory/Future) (Figure 2.3). Bilateral superior parietal/precuneus, anterior cingulate cortex, dorsomedial prefrontal cortex, and medial prefrontal cortex all showed greater activity during trials with high location detail than low location detail during Memory trials (Table S2.3). Conversely, there were no regions showing greater activity for high than low location details during Future Thinking trials. In line with the results of the location ratings, Memory trials revealed greater activity for High > Low clarity of the arrangement of people in a number of regions, including L superior parietal lobule into the precuneus, posterior cingulate, dorsolateral prefrontal cortex, posterior inferior temporal gyrus, early visual cortex, bilateral precentral and middle frontal gyri, inferior occipital cortex, occipitotemporal cortex, and the lingual gyrus (Table S2.4). In contrast, no regions were identified as tracking High > Low clarity of arrangement of people during Future Thinking trials. We extract these parameter estimates from each region identified across Memory High Location clarity ratings > Memory Low Location clarity ratings (Figure 2.4; Tables S2.5 & S2.6) and for the same contrast from the clarity of arrangement of people ratings (Figure 2.5; Tables S2.7 & S2.8) to demonstrate the specificity of these effects across conditions. We found that none of the regions identified by these memory contrasts showed any difference between Future Thinking high and low ratings (all *p*s > .05; note that these tests are independent of those used to define each ROI).

Figure 2.2 Results of Univariate Analyses



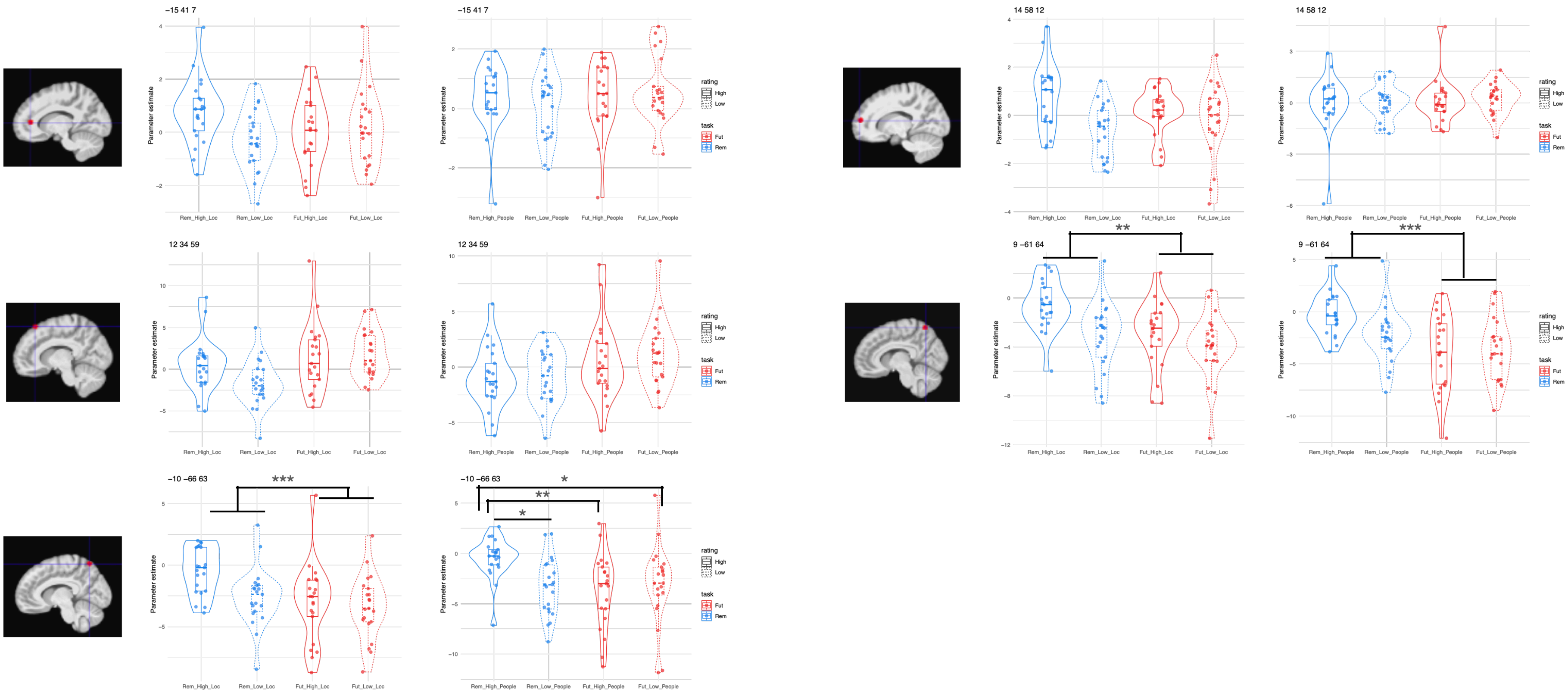
Note. A.) A contrast of Memory + Future > Sentence used to identify the core network. B.) Future > Memory contrast identifying the frontal pole, lateral temporal, and posterior cingulate. C.) A contrast of Memory > Future Thinking, identifying the precuneus, early visual cortex, mid cingulate, and dorsolateral prefrontal cortex.

Figure 2.3 Results of the median split analysis across ratings



Note. A.) Regions identified by the contrast comparing Memory High Clarity of Location > Memory Low Clarity of Location trials. These included the bilateral precuneus and medial prefrontal cortex. B.) Regions identified by the contrast comparing Memory High Clarity of Arrangement of People > Memory Low Clarity of Arrangement of People trials. These regions include the precuneus, early visual cortex, fusiform gyrus, and dorsolateral prefrontal cortex.

Figure 2.4 Parameter estimates across tasks in ROIs identified by Memory Location ratings High > Low



Note. Parameter estimates extracted and plotted from the median split analysis in each region of interest identified by the contrast High Location Rating > Low Location Rating in Memory trials (Fig 2.3A). Blue bars denote Memory trials, while red bars denote Future Thinking trials. High_Loc and Low_Loc refer to trials in which the clarity of location was rated high or low, respectively. High_People and Low_People refer to trials in which the clarity of arrangement of people was rated high or low, respectively. *p*<.05 *, *p*<.01 **, *p*<.001 ***.

Figure 2.5 Parameter estimates across tasks in ROIs defined by Memory Arrangement of People ratings High > Low

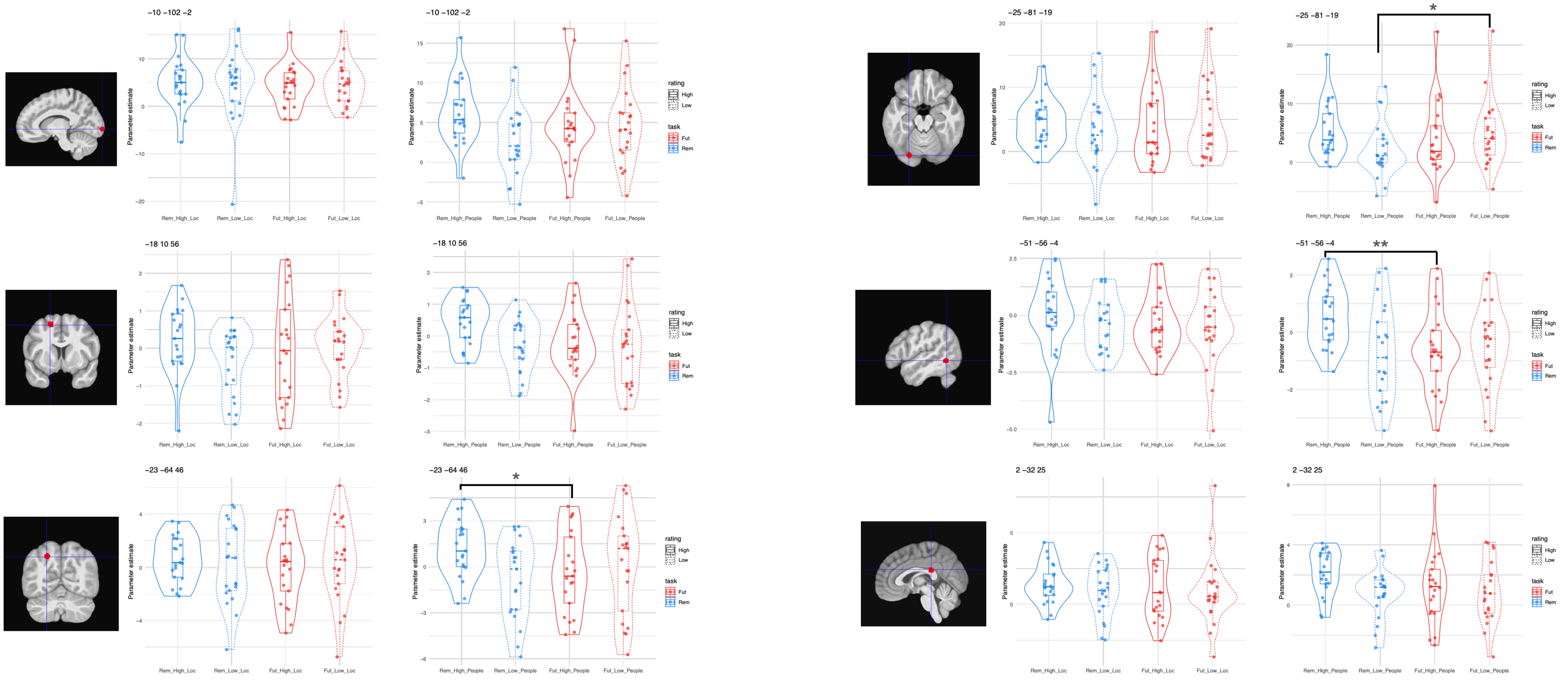
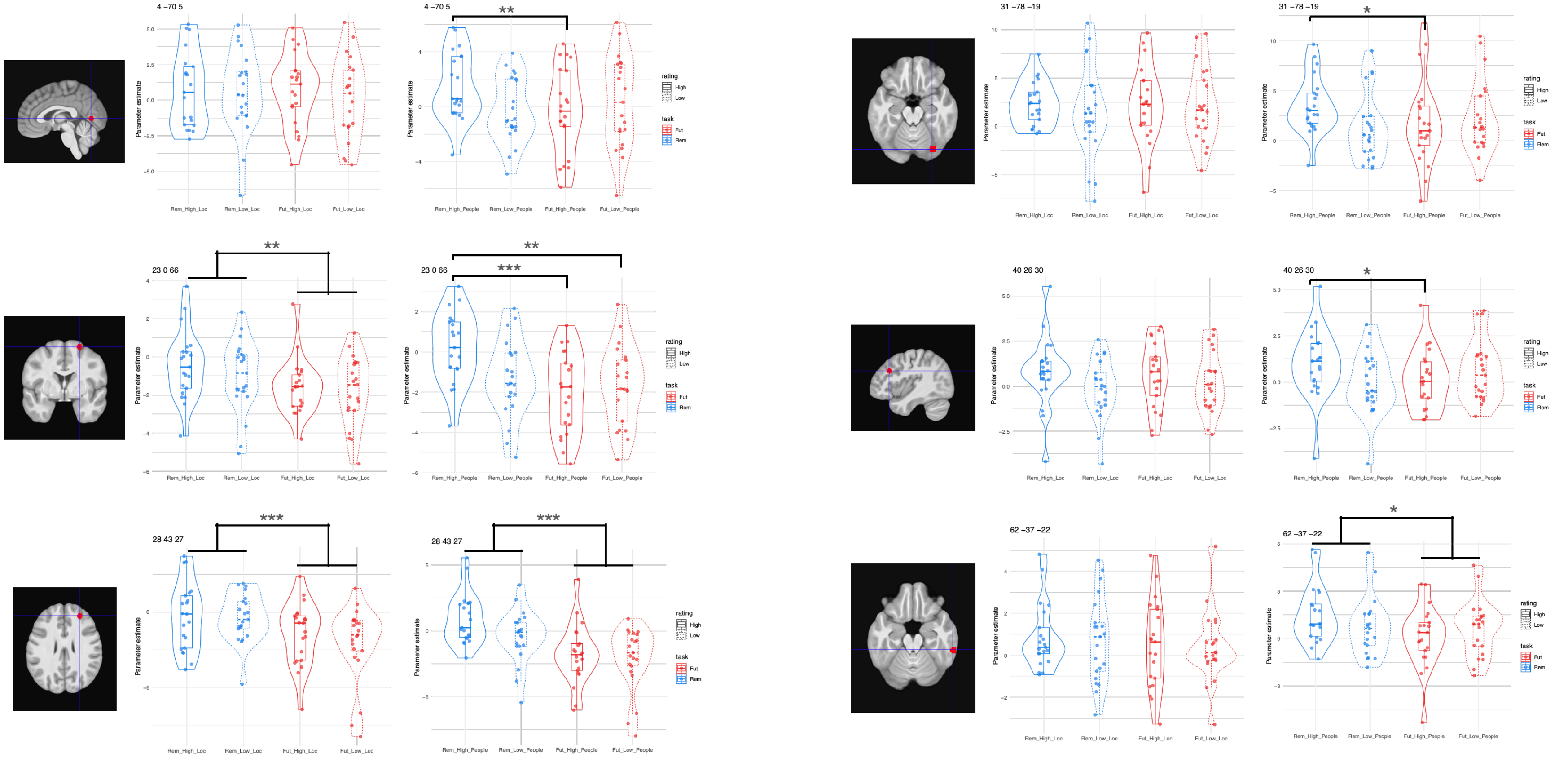


Figure 2.5 continued.



Note. Parameter estimates extracted and plotted from the median split analysis in each region of interest identified by the contrast High People Rating > Low People Rating in Memory trials (Fig 2.3B). Blue bars denote Memory trials, while red bars denote Future Thinking trials. High_Loc and Low_Loc refer to trials in which the clarity of location was rated high or low, respectively. High_People and Low_People refer to trials in which the clarity of arrangement of people was rated high or low, respectively. * *p*<.05, ** *p*<.01, *** *p*<.001.

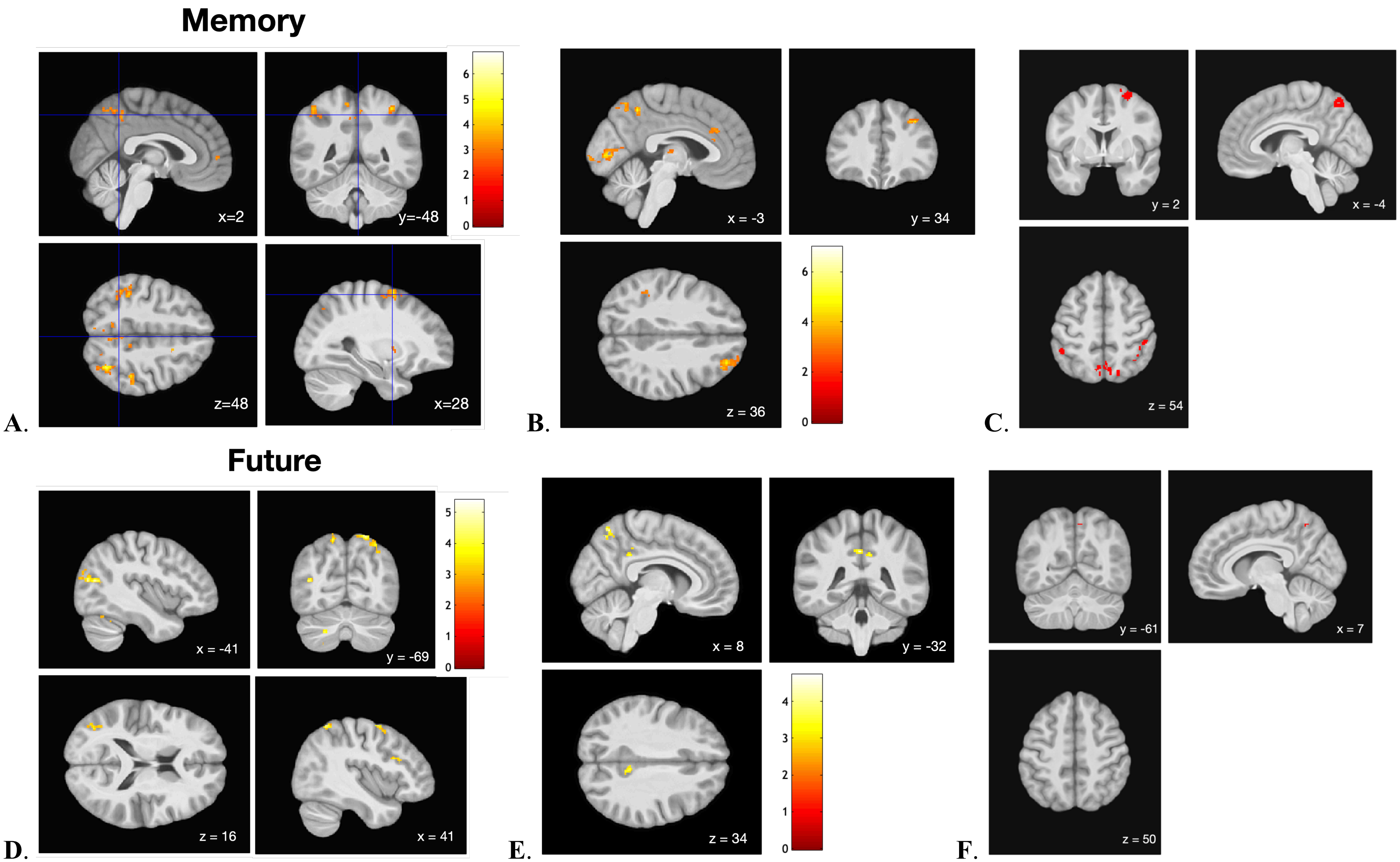
The above analyses demonstrate that there is a more substantial neural distinction between high and low subjective spatial context ratings for Memory than Future Thinking. However, because the trials contributing to the clarity of location and clarity of arrangement of people are not necessarily independent from each other, we conducted a parametric modulation analysis to allow us to compare across these rating content types.

These parametric modulation analyses revealed regions that independently tracked the clarity of location rating and the clarity of arrangement of people rating in each task (Figure 2.6). Activity in the superior parietal cortex, precuneus, frontal eye fields, and medial prefrontal cortex parametrically tracked the clarity of location rating in Memory trials (Table S2.9), while the superior parietal cortex, premotor cortex, inferior frontal gyrus, and occipital cortex tracked the clarity of location rating in Future trials (Table S2.10). A similar set of regions emerged when probing the clarity of arrangement of people ratings. Activity in dorsolateral prefrontal cortex, anterior cingulate, lingual gyrus, frontal eye fields, and the precuneus tracked the clarity of arrangement of people ratings during Memory trials (Table S2.9), while the posterior cingulate cortex and precuneus were modulated by the clarity of the arrangement of people during Future trials (Table S2.10).

In order to assess common regions tracking these two ratings, we found the intersection of the parametric modulation for clarity of the location and arrangement of people during Memory trials. This analysis revealed that, during Memory, spatial clarity ratings for both location and arrangement of people were associated with activity in the right frontal eye fields, bilateral superior parietal lobule, and bilateral precuneus. During Future Thinking, the intersection of both spatial clarity ratings tracked activity in the right precuneus.

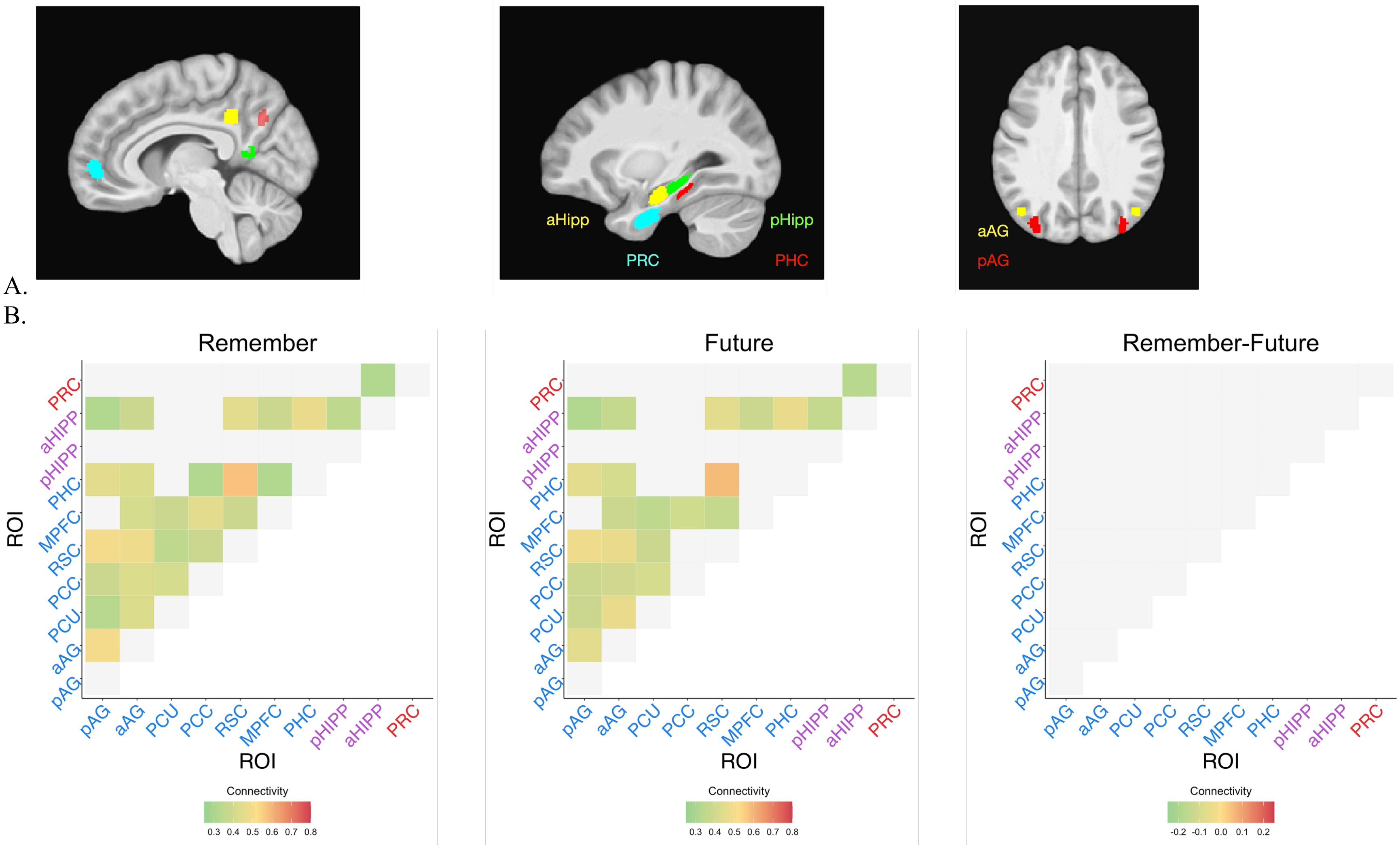
Finally, we sought to compare the background connectivity dynamics during Memory with those during Future Thinking. After regressing out trial- and behavior-related activity and nuisance variables, we calculated the HRF-weighted correlation between the time series of each ROI. This left us with the connectivity values related to the background covariation within each ROI, separately from trial and behavioral factors that could change activity in each region. We found moderate correlations between posterior-medial ROIs during both Memory (Figure 2.7(b)) and Future Thinking trials (Figure 2.7(c)). There were no connections that were significantly greater during Memory than Future Thinking (Figure 2.7(d)).

Figure 2.6 *Results of parametric modulation analyses identifying regions tracking subjective ratings in Memory and Future Thinking*



Note. A.) Regions parametrically modulated by the clarity of the location rating during memory trials. B.) Regions parametrically modulated by the clarity of arrangement of people during memory trials. C.) The intersection between A. and B. D.) Regions parametrically modulated by the clarity of the location during future trials. E.) Regions parametrically modulated by the clarity of arrangement of people during future trials. F.) The intersection of D. and E.

Figure 2.7 Task background connectivity between episodic retrieval and future thinking



Note. A.) Regions of interest entered into this analysis. B,) ROI-to-ROI Connectivity matrices among the regions specified in A. for Memory trials, Future Thinking trials, and the difference between the two.

Discussion

In the present study, we probed the brain networks supporting episodic retrieval and future thinking to evaluate how they dissociate across these tasks and across levels of spatiocontextual detail. With a univariate analysis, we replicated findings of BOLD activation in the core network common to memory retrieval and future thinking as well as increased activity during future thinking compared with episodic retrieval in the frontal pole and right inferior frontal gyrus, among other regions (Addis et al., 2007). Although few other studies have reported greater activity for episodic retrieval than future thinking (Addis et al., 2009; Weiler et al., 2010), we identified a number of regions through this contrast, including the bilateral dorsolateral prefrontal cortex, insula, mid-cingulate cortex, the cuneus, and inferior occipital gyrus, and inferior parietal lobule. Some of these regions replicate the findings of Addis et al. (2009) and Weiler et al. (2010); namely, broad swaths of lateral and medial occipital cortex and the inferior parietal lobule. Activity in these regions is thought to reflect the heightened visual and contextual detail during episodic retrieval compared to future thinking (D'Argmebeau & van der Linden, 2004) in accordance with a *recapitulation* account, which states that, during remembering, the perceptual regions that originally processed the information are reactivated during retrieval of that information (e.g. Kahn et al., 2004). Such recapitulation is also thought to contribute to the increased subjective quality of mental imagery, as greater neural overlap between perception and mental imagery has been found to correlate with the experienced vividness of that imagery (Dijkstra et al., 2017).

Most studies that report this contrast do not find any regions with greater activity during episodic retrieval than future thinking (Addis et al., 2007; Szpunar et al., 2007; Szpunar et al., 2009). It is possible that we see this effect whereas others have not because of the task demands introduced by the subjective ratings in the present task. By prompting participants to consider the spatiocontextual features in each event to make their ratings, they may have become attuned more to visuospatial aspects of that event, which are known to contain more detail during episodic retrieval than future thinking (D'Argembeau & van der Linden, 2004).

Evaluating this behavioral difference between tasks with a median split analysis revealed a set of regions that tracked the clarity of location ratings during memory trials, but no significant activity that tracked the clarity of location during future thinking trials. Parallel results emerged for the clarity of arrangement of people ratings: a broad set of regions were more active for High>Low clarity of arrangement of people during memory trials, but we did not find regions that tracked this difference during future thinking. When extracting parameter estimates from these regions, we found that none of these regions identified by Remember High Rating > Remember Low Rating contrasts for both location and people showed a difference between Future High and Future Low ratings. This finding demonstrates that a set of regions tracks these spatial clarity ratings uniquely during memory retrieval but not episodic future thinking. The parametric modulation analysis converged on this point, as no common regions were found that tracked either clarity rating across both tasks. When interrogating the parameter estimates from the ROIs extracted from the location contrast, the precuneus bilaterally showed Remember > Future effects across both high and low location ratings. The right precuneus also showed a Remember > Future main effect across people ratings, and there was an interaction in the left precuneus such that the Remember high people rating condition was greater than all other conditions. These findings suggest that the precuneus is tracking a meaningful difference between episodic retrieval and future thinking that, at least during retrieval, is related to the spatiocontextual detail in an event.

Moreover, during the median split analyses, we found that dorsolateral prefrontal cortex, anterior cingulate cortex, frontal eye fields, and precuneus showed greater activity during Memory trials with high clarity of arrangement of people trials than Memory trials with low clarity of arrangement of people. Subsequent parametric modulation analyses demonstrated commonalities in the regions with activity modulated by the clarity of location and arrangement of people. Namely, activity in the frontal eye fields, bilateral superior parietal lobule, and precuneus during Memory was modulated by both the clarity of location and clarity of arrangement of people ratings, while a small cluster in the precuneus was modulated by both the clarity of location and clarity of arrangement of people ratings during Future Thinking. These converging results highlight a burgeoning line of inquiry into the role of the visual oculomotor system in episodic retrieval and future thinking (see Conti & Irish, 2021 for review). Oculomotor behavior includes orienting one's gaze and executing saccades; it is thought to be mediated by the frontal eye fields, lateral intraparietal area, and superior colliculus which create a map-like representation to guide the timing and placement of eye movement, and the dorsolateral prefrontal cortex (dlPFC), anterior cingulate, and supplementary eye fields which coordinate cognitive control of these behaviors (Ryan et al., 2020). Eye-tracking research has demonstrated that greater similarity between the path of one's gaze at encoding and retrieval leads to improved objective memory performance, as well as subjective memory strength (Holm & Montyla, 2007; Ryals et al., 2015). Moreover, macaque work suggests that the precuneus is structurally connected to the oculomotor system, including the frontal eye fields (see Cavanna & Trimble, 2006 for review). The finding that the precuneus parametrically tracked spatial detail about both people and locations is concordant with prior research demonstrating that repeated simulation of different features of an event (people and objects) drives increased activity in the precuneus

(Szpunar, St. Jacques, et al., 2014). Szpunar, St. Jacques, et al. interpreted this finding as possibly reflecting that the precuneus tracks an aspect of an event that correlate with repetition, with one possibility being subjective detail (Cavanna & Trimble, 2006). The present work lends support to this idea, as the precuneus tracked subjective spatial detail, agnostic to event features (locations and people). Taken together, a parsimonious account of these findings is that the oculomotor system supports the distinct spatial phenomenology of episodic retrieval, while the precuneus tracks a signal of internal vividness as the component parts of an event are reassembled by the posterior medial network. Additional studies will be needed to provide strong tests of this account.

Although these study findings are informative, it is important to consider the limitations. Across multiple analyses, including a univariate analysis, median-split, and parametric modulation, we do not find evidence converging with that of Gilmore et al. (2016) that activity in the retrosplenial complex or parahippocampal cortex supports the greater spatial detail of episodic retrieval compared to future thinking. This unexpected outcome might be due to differences in task demands between our paradigms. Gilmore et al. (2016) cued participants to think about past and future events when cued by words or phrases describing objects, locations, or activities (e.g. *bowling* or *lottery*), whereas participants in the present study were cued with personally relevant details from their own life that they provided during the first study visit. The latter procedure likely greatly reduced the constructive demands, as participants did not need to invoke a search process to determine where and with whom an event would take place prior to elaborating on that event. While we predicted that we would see greater connectivity among posterior medial ROIs during memory than future thinking, especially between the retrosplenial complex and parahippocampal cortex, that prediction was also not borne out in the data. In addition to these task demands concerns described above, it is also possible that the behavioral differences in subjective experience between memory and future thinking are not instantiated in the connectivity pattern between these two tasks. As it stands, this background connectivity analysis demonstrates parallels between episodic retrieval and future thinking in posterior medial connectivity dynamics.

In sum, this study aimed to characterize the neural underpinnings of the unique subjective spatial detail in episodic retrieval. We found greater activity during episodic retrieval than future simulation in the precuneus, visual cortex, mid-cingulate, and dlPFC. Through two analysis streams, we probed the regions that tracked subjective spatial clarity in these regions, finding that visual and oculomotor regions independently support the clarity of spatial detail about locations and people, while the precuneus tracks an integrated signal of spatial clarity across both detail types.

Chapter 4: Paper 3

Modulation of hippocampal brain networks produces changes in episodic simulation and divergent thinking

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Abstract

Prior functional magnetic resonance imaging (fMRI) studies indicate that a core network of brain regions, including the hippocampus, is jointly recruited during episodic memory, episodic simulation, and divergent creative thinking. Because fMRI data are correlational, it is unknown whether activity increases in the hippocampus, and the core network more broadly, play a causal role in episodic simulation and divergent thinking. Here we employed fMRI-guided transcranial magnetic stimulation (TMS) to assess whether temporary disruption of hippocampal brain net- works impairs both episodic simulation and divergent thinking. For each of two TMS sessions, continuous θ-burst stimulation (cTBS) was applied to either a control site (vertex) or to a left angular gyrus target region. The target region was identified on the basis of a participant-specific resting-state functional connectivity analysis with a hippocampal seed region previously associated with memory, simulation, and divergent thinking. Following cTBS, participants underwent fMRI and performed a simulation, divergent thinking, and nonepisodic control task. cTBS to the target region reduced the number of episodic details produced for the simulation task and reduced idea production on divergent thinking. Performance in the control task did not statistically differ as a function of cTBS site. fMRI analyses revealed a selective and simultaneous reduction in hippocampal activity during episodic simulation and divergent thinking following cTBS to the angular gyrus versus vertex but not during the nonepisodic control task. Our findings provide evidence that hippocampal-targeted TMS can specifically modulate episodic simulation and divergent thinking, and suggest that the hippocampus is critical for these cognitive functions.

Keywords: episodic memory, creativity, imagination, TMS, fMRI

Introduction

Episodic memory (i.e., the ability to remember specific events from the past) (Tulving, 2002) is a constructive process whereby the individual elements of a past event are linked together at the time of retrieval (Bartlett, 1932; Schacter et al., 1998). During the past decade numerous studies have indicated that there are neurocognitive similarities between episodic memory and episodic simulation (i.e., the ability to imagine a novel and specific future episode) (for reviews, see Schacter et al, 2012, 2017). These similarities have been taken as support for the constructive episodic simulation hypothesis (Schacter & Addis, 2007, 2020). According to this hypothesis, the cognitive and neural similarities reflect to a large extent the role of episodic memory in supporting simulations of the future, in that episodic retrieval processes allow for the flexible recombination of elements of past episodes to construct novel future events.

Several branches of evidence support this hypothesis. Studies employing functional magnetic resonance imaging (fMRI) demonstrate the existence of a common set of neural regions (i.e., the "core network") engaged during episodic remembering and imagining (for review, see Benoit & Schacter, 2015). This set of regions, which largely overlaps with the default network (Raichle, 2015), includes the medial temporal lobe (e.g., hippocampus), lateral parietal cortex (e.g., bilateral angular gyrus [AG]), medial parietal cortex, and medial prefrontal cortex (among others). Because fMRI is a correlational technique, recent studies have also employed repetitive transcranial magnetic stimulation (rTMS) to demonstrate a causal role of the core network during episodic memory retrieval and simulation. In one study (Thakral et al., 2017), rTMS was applied to the left AG. Following rTMS disruption to the left AG, relative to rTMS to a control site (vertex), participants generated fewer episodic/internal details (the who, what, when, and where of an episode) (Levine et al., 2002) when remembering past and imagining novel future episodes. Critically, this effect was selective to episodic information, as performance in a nonepisodic control task did not differ as a function of TMS site. In addition, behavioral studies support the idea that remembering and imagining share common cognitive processes. One line of work used an episodic specificity induction (ESI), or brief training in recollecting specific details from a recent experience, to examine the role of episodic retrieval in related cognitive processes, such as simulating future experiences (for review, see Schacter & Madore, 2016). After receiving the ESI, relative to a control induction, participants subsequently remember and imagine episodes in greater episodic detail but show no differences on tasks that do not draw on episodic processing (e.g., describing a picture or defining and comparing words) (Madore et al., 2014; Madore & Schacter, 2016).

Related studies have revealed a role for episodic retrieval in other cognitive functions that do not require episodic memory, but may still be influenced by it. One such cognitive function is divergent thinking, or the ability to generate creative ideas by combining diverse kinds of information in novel ways (Guilford, 1967). For example, 1) episodic memories are sometimes drawn upon during divergent thinking (Gilhooly et al., 2007; Runco & Acar, 2010; Storm & Patel, 2014), 2) patients with memory impairments show deficits on divergent thinking (Duff et al., 2013), 3) participant-level correlations have been observed between the amount of episodic detail in imagined future episodes and performance on divergent thinking (Addis, Pan, et al., 2016), and 4) the ESI selectively boosts performance on divergent thinking (Madore et al., 2015; Madore, Jing, et al., 2016) relative to tasks that do not engage divergent thinking. Paralleling these behavioral links, several neuroimaging studies have demonstrated that core network regions, such as the hippocampus, are engaged during episodic memory, simulation, and divergent thinking (Beaty et al., 2018; Ellamil et al., 2012; Wu et al., 2015). fMRI studies have also demonstrated that the hippocampus, among other core network regions, is linked to ESI-related increases in episodic detail production in imagined future events and divergent thinking (Madore et al., 2019; Madore, Szpunar, et al., 2016).

Taken together, these findings suggest that episodic retrieval plays a role in supporting episodic simulation and divergent thinking, but multiple caveats call this conclusion into question. First, although episodic memories are drawn upon during divergent thinking, they appear infrequently (e.g., Gilhooly et al., 2007). Second, the data from neuropsychological studies (e.g., Duff et al., 2013) require interpretive caution because patients often exhibit deficits in both episodic and semantic memory. Third, ESI-related evidence stems from a global manipulation of episodic processing, and it is also unclear whether the hippocampus, or other brain regions involved in episodic retrieval, underlie the manipulation's efficacy (Madore et al., 2019; Madore, Szpunar, et al., 2016). Fourth, given the correlational nature of fMRI, it is unknown whether any of the common neural activity observed across remembering, imagining, and divergent thinking reflects a necessary role of the common regions (e.g., Beaty et al., 2018).

The aim of the present study was to provide a causal test of the role of hippocampally dependent episodic retrieval in future imagining and creative thinking by using fMRI-guided TMS in the form of continuous θ-burst stimulation (cTBS) to disrupt neural activity in the hippocampus, which has been consistently engaged during episodic memory, simulation, and divergent thinking. For each of two TMS sessions, cTBS was applied to either a control site (vertex) or to a left AG target region. Critically, the target region was identified on the basis of a participant-specific resting-state functional connectivity analysis with a hippocampal seed region previously associated with episodic memory, simulation, and divergent thinking (Benoit & Schacter, 2015; Wu et al., 2015). Previous research has shown that TMS in the vicinity of our target region impacts activity in connected regions, including the hippocampus (Wang et al., 2014). Following application of cTBS, participants underwent fMRI and performed three tasks. In each task, participants were shown an object word and either imagined a related personal event in the next few years (episodic simulation task), generated creative and unusual object uses (the alternate uses task [AUT], or divergent thinking task), or generated associated objects and their definitions (nonepisodic control task). Following scanning, participants verbally generated their thoughts for each task cue.

Based on our prior rTMS findings (Thakral et al., 2017), we predicted that cTBS to a core network region (the left AG) would produce a selective impairment in the generation of episodic details during simulation, with no deficit in the nonepisodic control task. We then tested whether cTBS would also produce a deficit in divergent thinking. Critically, we hypothesized that cTBS-related differences in the episodic detail of imagined events and the number of creative uses produced for the divergent thinking task would be linked to changes in neural activity in the hippocampus (and possibly the core network more broadly). Finally, we employed a resting-state functional connectivity analysis with the hippocampal coordinate as the seed and the TMS site as the target. This analysis assessed whether cTBS caused the left AG and the hippocampus to become less synchronized with each other, thus demonstrating that reduced coupling between these two brain regions led to reduced ability to think creatively and to imagine an episodic future event.

Methods

Participants

Informed consent was obtained from all participants prior to participation, with protocol approval from the Institutional Review Board of Harvard University. Nineteen undergraduate and graduate students from the local community were consented. One person was excluded due to falling asleep in the scanner, leaving *n* = 18 in the analyzed sample (mean ± [1 SE] age of 21.2 ± 0.38 y; range of 19 to 26 y; 14 females). All participants self-reported to be native English speakers and right-handed, with normal or corrected-to-normal vision. See Supplementary Materials for additional TMS-specific recruitment parameters. An a priori sample size of 18 was chosen based on recent fMRI-TMS within-participant studies of the left lateral parietal cortex and episodic memory (Nilakantan et al., 2017; Wang et al., 2014; see also Sestieri et al., 2013; Thakral et al., 2017), and to also provide a full counterbalanced set.

Experimental Design Overview

A three-session within-participants design was used to assess the influence of inhibitory cTBS on hippocampal brain networks during episodic simulation and divergent thinking. Each session lasted ∼3 h and occurred on a different day (mean delay between each session was 5.5 d, with the restriction that all three sessions were done in ∼2 wk). In session 1, participants came to the laboratory for fMRI only, where they completed: 1) two task runs alternating between episodic simulation, divergent thinking, and nonepisodic control tasks; 2) a resting-state scan; and 3) an anatomic scan (in that order). On each task trial, participants viewed an object word cue, and for each cue generated a novel and specific future event (i.e., the episodic simulation task), alternate uses of the object (i.e., the divergent thinking task, AUT), or a sentence with typical associates of the object, their meanings, and definitions (i.e., the nonepisodic control task). Before scanning, participants were instructed on and practiced the three tasks. Sessions 2 and 3 involved cTBS and were similar to session 1, with the exception that an anatomic scan was not collected and, before participants entered the scanner, cTBS was applied to the control site (vertex) or the AG target. The AG target was identified on the basis of a resting-state functional connectivity analysis (i.e., a seed-to-voxel analysis) using the resting-state scan from session 1, with the left anterior hippocampus as the seed (i.e., a hippocampal coordinate previously associated with episodic memory, simulation, and divergent thinking; see below). Following fMRI data collection in each session, participants completed a postscan interview about their thoughts for each scanning cue. The order of cTBS site (vertex or AG) was counterbalanced across participants, and different object cue words were used across each session.

With the exception of the resting-state analyses, behavioral and fMRI analyses were restricted to effects between the vertex and AG cTBS sessions for two primary reasons. First, the order of cTBS session (i.e., no-cTBS, vertex, AG vs. no-cTBS, AG, vertex) was randomly assigned across participants (with half receiving vertex second and half AG second). Thus, differences associated with task familiarity (i.e., practice) between the vertex and AG cTBS sessions were controlled (relative to performance being expectedly lower in the no-cTBS session as it necessarily came first). Second, a comparison of data between the vertex and AG cTBS sessions controls for nonspecific cTBS effects (see also Thakral et al., 2017). All results are collapsed across cTBS session order (i.e., vertex cTBS followed by AG cTBS, and vice versa). For all significant results (at the $P < 0.05$ level), we report the relevant effect sizes (partial η^2 in the case of F tests, d for t tests) and in cases where $P < 0.001$, we report as such.

Experimental Materials and Procedure

Main Tasks

Further information on object cue words and task presentation are contained in the Supplementary Materials. In each session, participants completed three fMRI runs. In two initial task runs, participants viewed 54 object cues and completed the main tasks (episodic simulation, divergent thinking, and nonepisodic control), and for the last run participants completed a resting-state scan. Each task run was ∼11 min and included a pseudorandom presentation of nine trials per task (for a total of 27 trials in each run) with the constraint that no more than two trials per task were presented in succession. For task trials (Fig. 3.1), the screen showed three lines of text for 15 s (first line: task; second line: instruction reminder; and third line: object cue word). On each trial, participants were presented with the construction–elaboration paradigm for 15 s (see below), followed by two separate ratings each presented for 2.5 s. The trial then ended with a variable fixation period (jittered at 2, 4, and 6 s). Ratings were made with a five-button response box in their left hand. Each fMRI run began and ended with a 5-s fixation period.

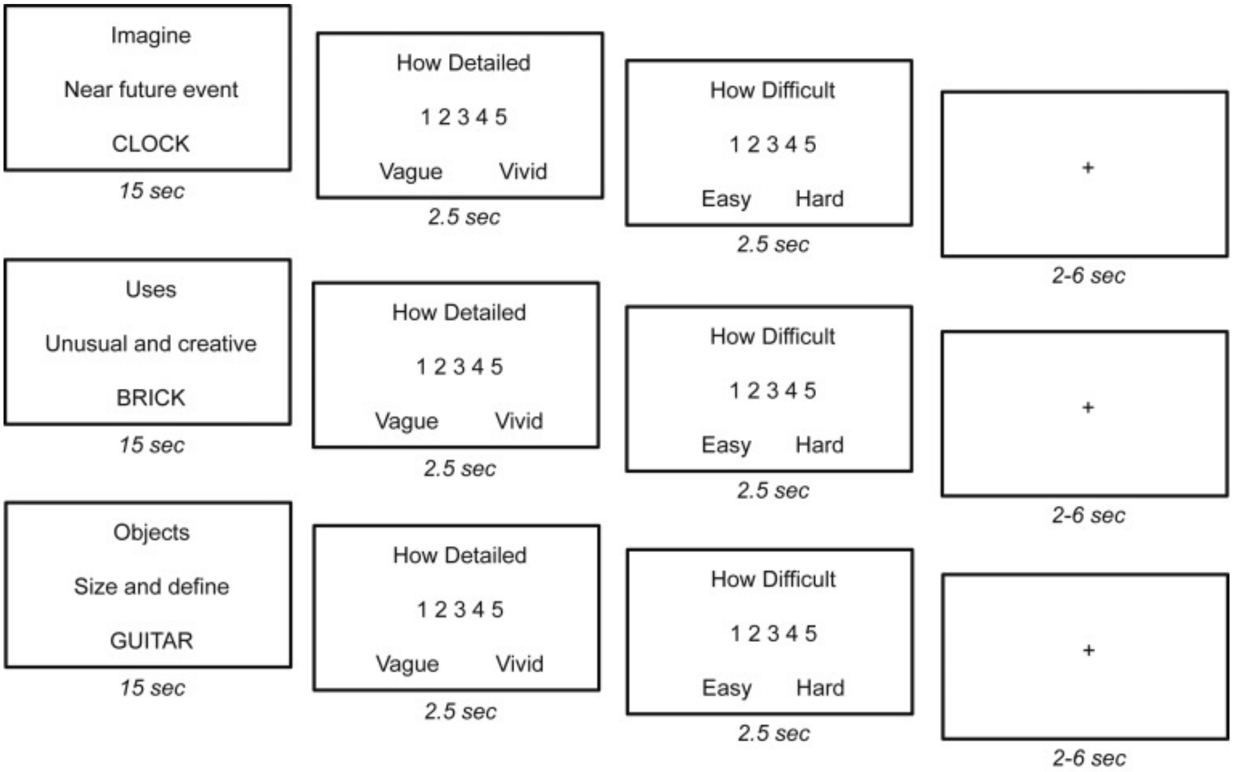
For simulation trials (Fig. 3.1, *Top*), participants were instructed to silently imagine a novel and specific future episode from a first-person perspective related to the cue. Each event had to occur in the next few years, be specific in time and place over the course of a few minutes to an hour (i.e., an episodic event), and be as detailed as possible. With respect to construction–elaboration, participants pressed their thumb when the future event had come to mind (i.e., been constructed), following which they filled in all of the details and elaborated on the event until the first rating appeared. These details included—but were not limited to—the people, actions, and emotions of the event. At the end of each simulation trial, participants first rated the level of vividness or amount of subjectively rated detail associated with the event they had generated on a 5-point scale (“least vivid with no or few details” to “very vivid and highly detailed”), followed by the level of difficulty on a 5-point scale (“very easy” to “very difficult”).

For divergent thinking trials (Fig. 3.1, *Middle*), participants were instructed to silently generate as many unusual and creative uses related to the cue during its 15-s presentation. Participants were told to be both creative and to generate as many uses as possible given past research indicating that type of instruction can impact divergent thinking (e.g., Nusbaum et al., 2014). With respect to construction–elaboration, participants pressed their thumb when they had generated their first creative use (i.e., constructed it), following which they were to generate as many additional uses as possible until the first rating appeared. At the end of each divergent thinking trial, participants first rated the level of vividness or amount of subjectively rated detail associated with the uses they had generated on a 5-point scale ("least vivid with no or few details" to "very vivid and highly detailed"), followed by the level of difficulty on a 5-point scale (i.e., "very easy" to "very difficult").

For nonepisodic control trials (Fig 3.1, *Bottom*), participants were first instructed to silently generate two associated objects related to the cue word, and then to put all three in a sentence sorting the objects by their relative physical size. With respect to construction–elaboration, participants pressed their thumb when they had generated the size sentence, following which they generated meanings and definitions for each object in as much detail as possible. Participants were instructed to focus on meaning and definition details, which included but were not limited to typical attributes, functions, and characteristics. They were also told to generate details as if they were coming from a dictionary or encyclopedia rather than related to themselves or their lives. At the end of each control trial, participants first rated the level of detail associated with the meanings and definitions they had generated on a 5-point scale ("least vivid with no or few details" to "very vivid and highly detailed"), followed by the level of difficulty ("very easy" to "very difficult"). Here, the nonepisodic control task was chosen as a comparison to both simulation and divergent thinking as it requires the search, retrieval, and integration of information related to an object cue, but did not involve the generation of a coherent episodic event or divergent thinking (see analogous control tasks in prior studies as a comparison to both episodic memory/simulation and divergent thinking) (Addis et al., 2007;

Benoit & Schacter, 2015; Madore et al., 2015; Madore, Szpunar, et al., 2016; Madore et al., 2019; Thakral et al., 2017; Thakral, Madore, & Schacter, 2020).

Figure 3.1 *Experimental Design*



Note. In each task participants were shown an object word for 15 s. For the episodic simulation task (Top), participants were asked to silently imagine a novel future experience related to the object. For the divergent thinking task (Middle), participants were asked to generate creative and unusual uses for the object. For the control task (Bottom), participants were asked to generate two associated objects, put them in a sentence by their relative size, and then generate definitions related to the objects. After each trial, participants rated the level of detail and difficulty on a 5-point scale. The trial ended with a variable fixation period.

Resting State

After the two main task runs, participants completed a resting-state scan for 7 min and 8 s (for similar procedures, see Madore et al., 2019; Madore, Szpunar, et al., 2016). During this scan, participants were shown a white central fixation cross on a black screen and were instructed to keep their eyes open for the scan.

Postscan Interview

Immediately after scanning, participants completed a postscan interview where they viewed each object cue from the scanner and were instructed to verbally generate whatever they had thought about for each cue (for similar postscan procedures, see Addis et al., 2007; Madore et al., 2019; Madore, Szpunar, et al., 2016; Madore & Schacter, 2016). They were specifically instructed to not add anything they had not thought about. Each trial was self-paced, and participants hit the space bar when they had finished speaking. Following each trial, participants made additional ratings regarding their responses (more details are contained in the Supplementary Materials).

Participants' verbal responses were audio-recorded and transcribed for analysis. For the episodic simulation task, each future event was scored in accordance with the Autobiographical Interview (Levine et al., 2002). For the nonepisodic control task, meanings and definitions were also segmented into internal and external details (Madore, Szpunar, et al., 2016; Madore & Schacter, 2016). Finally, for the divergent thinking task, we computed standard measures related to the quantity and quality of the uses (Addis, Pan, et al., 2016; Guilford, 1967; Guilford et al., 1960; Madore et al., 2015, 2019). More details on scoring criteria are included in the Supplementary Materials. All scoring was conducted by two raters who were blind to cTBS session (i.e., no-cTBS, vertex, or AG). We confirmed interrater reliability with a separate and third rater who scored a random selection of ~25 responses randomly sampled from each task and cTBS session and obtained high interrater reliability (Cronbach's α > 0.90 across the divergent thinking measures, and internal and external details for the episodic simulation and control task).

fMRI Acquisition and Analysis

Univariate analysis

Anatomic and functional images were acquired on a 3-Tesla Siemens scanner with a 32-channel head coil, and handled with standard preprocessing steps in Statistical Parametric Mapping (SPM12, Wellcome Department of Cognitive Neurology, London, United Kingdom). The Supplementary Materials contain additional information on scanning and preprocessing parameters. Univariate analysis was conducted using a two-stage mixed effects general linear model (GLM). In the first stage, neural activity associated with the construction and elaboration periods were modeled separately for each simulation, divergent thinking, and control trial using the canonical hemodynamic response function in SPM12 (for similar univariate analyses, see Addis et al., 2007; Madore, Szpunar, et al., 2016). The construction period was modeled with a delta/stick function 2 s after cue onset, and the elaboration period with a delta/stick function 2 s after participants made a button response (mean [±1 SE] construction time of 5.09 ± 0.39 s across tasks and cTBS conditions).[‡] The associated blood-oxygen level-dependent (BOLD) response was modeled by convolving the boxcar functions with a canonical hemodynamic response function to yield regressors in a GLM that modeled the BOLD response for each event type. Each first-level model comprised 12 events modeling neural activity as a function of task (episodic simulation, divergent thinking, and nonepisodic control), cTBS site (vertex and AG), and trial phase (construction and elaboration). Two additional events of no-interest included trials without a response and the rating period. Six regressors modeling movement-related variance were also included in the first-level model (three for rigid-body translation and three for rotation). An autoregressive model of order 1 was used to correct for nonsphericity of the error covariance (Friston et al., 2002). The data across the two cTBS sessions were concatenated. Temporal smoothing was conducted before estimation of the parameter estimates using the default high-pass filter of 128 s. Note that, although we modeled the elaboration period of each trial, here we focus on construction-related neural activity as this portion of the trial has been associated with retrieval processes hypothesized to be shared across episodic simulation and divergent thinking (Addis, Pan, et al., 2016; Campbell et al., 2018; Madore et al., 2019; Madore, Szpunar, et al., 2016; Moscovitch et al., 2016; Thakral, Madore, Addis, et al., 2020; Thakral, Madore, & Schacter, 2020).

In the second stage, parameter estimates for the six events of interest (i.e., construction-related activity for each of the three tasks and two cTBS sites) and for each participant were entered into a repeated-measures ANOVA with participants modeled as a random effect. To evaluate effects within the hippocampus, a mask was created by manually tracing the hippocampus using the across-participant mean normalized anatomical image based on standard anatomical landmarks (Frisoni et al., 2015; for similar approaches, see Thakral et al., 2015; Thakral, Madore, Addis, et al., 2020). An individual voxel two-tailed threshold of $P < 0.005$ was used for targeted a priori contrasts aimed at identifying cTBS effects (see below) within the hippocampus (Johnson et al., 2008, 2013; Suzuki et al., 2011a, 2011b; Thakral et al., 2015; Thakral, Madore, & Schacter, 2020). Correction for multiple comparisons (to $P < 0.05$) was affected by imposition of a cluster extent threshold (Slotnick, 2017; Slotnick et al., 2003) of 16 voxels within the hippocampal mask. The threshold was estimated using a Monte Carlo simulation of 10,000 iterations with a full-width half-maximum (FWHM) of 7.65 mm estimated using the residual mean-square image of the participant-specific first-level models (i.e., the maximum FWHM across all images). For whole-brain analyses, an individual voxel two-tailed threshold of $P < 0.005$ was used, corrected to $P < 0.05$ by imposition of a cluster extent of 94 voxels (estimated using the same procedure as just described). All contrasts were conducted using the error term derived from the parent ANOVA.

Our aim was to assess whether the hippocampus in particular would demonstrate a common cTBS effect for both the episodic simulation and divergent thinking tasks. To formally test for the presence of such an effect, the vertex > AG contrast for the episodic simulation + divergent thinking > nonepisodic control was analyzed (i.e., the interaction contrast; for similar procedures, see Madore et al., 2019; Madore, Szpunar, et al., 2016). This interaction identifies regions exhibiting significant reductions in activity following cTBS to the AG compared with cTBS to the vertex during episodic simulation and divergent thinking, over the nonepisodic control task.

Resting-state analysis

Resting-state images were acquired on the 3-Tesla Siemens scanner with a 32-channel head coil, and preprocessed according to standard guidelines in FSL 4.1.7 (FMRIB) and SPM12 (see details in Supplementary Materials). A seed-to-voxel connectivity analysis was carried out on an individual participant basis (Van Dijk et al., 2010) to identify the left AG cTBS target functionally coupled to the hippocampal coordinate of interest. A 6-mm sphere was centered at the left hippocampal coordinate of $x = -25$, $y = -10$, $z = -19$ (Fig. 3.2A). This coordinate was selected on the basis of a prior metaanalysis demonstrating that the left hippocampus is associated with divergent relative to convergent thinking (Wu et al., 2015). Of importance, this coordinate overlapped the hippocampal cluster reported in a relevant metaanalysis to be jointly recruited during episodic memory and simulation (see Figure 2 and Table 3 in Benoit & Schacter, 2015). These findings support the assumption that the chosen hippocampal seed is associated with the three cognitive processes of interest. To create whole-brain correlation images for each individual participant and cTBS session, the averaged time series across all voxels comprising a seed region-of-interest (ROI) was used as the variable of interest with the time series corresponding to each voxel across the brain via Pearson's correlation; all statistical analyses of correlation data were performed on Fisher's z-transformations. Our resting-state analysis was based on two of our prior fMRI studies (Madore et al., 2019; Madore, Szpunar, et al., 2016). These two studies not only employed the same resting-state data acquisition protocols, but also the same resting-state analysis pipeline. Before conducting the present study, we ran pilot seed-to-target connectivity analyses on individual participant resting-state data from our prior studies to confirm that a 6-mm sphere was sufficient to identify left AG target sites on an individual participant basis. These pilot analyses determined that a 6-mm sphere together with the resting-state scanning protocol was sufficient, and therefore we adopted the identical procedures.

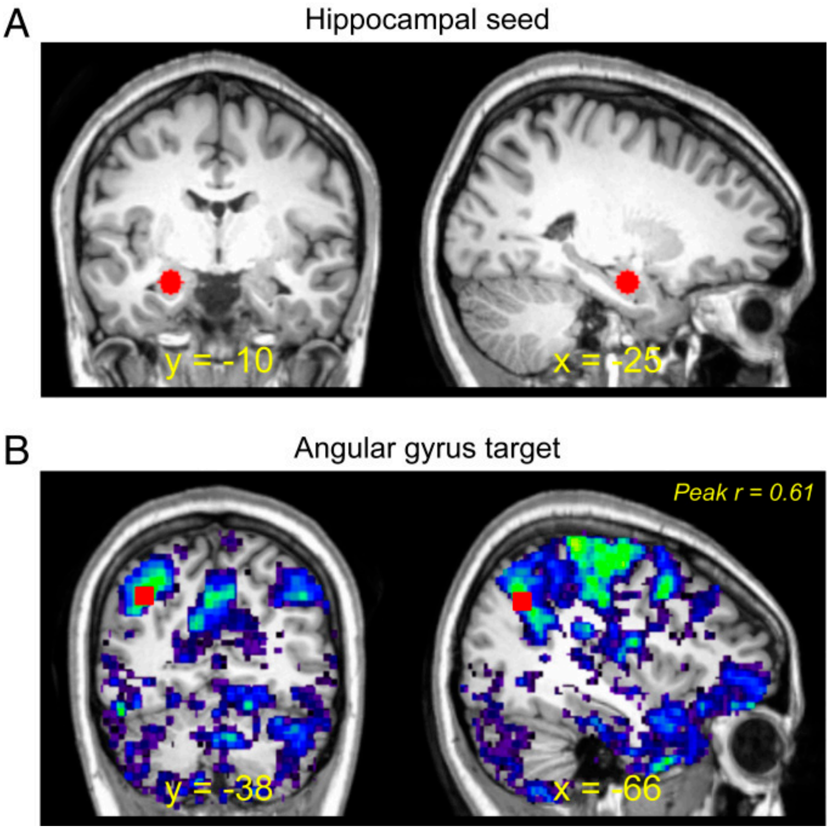
fMRI-TMS procedure

Following similar procedures employed in prior fMRI-TMS studies targeting hippocampal networks through the AG (e.g., Hermiller et al., 2019; Nilakantan et al., 2017; Tambini et al., 2018; Wang et al., 2014), the cTBS target was selected on an individual participant basis as the left AG coordinate with the strongest connectivity to the left hippocampal seed (i.e., highest correlation) (Fig. 3.2B). The coordinate had to fall within the left Brodmann area 39 (i.e., the left AG). Fig. 3.4A illustrates the cTBS targets across the entire sample (mean

AG cTBS coordinate [±1 SE] of x = −45.6 ± 1.45, y = −65.9 ± 0.70, z = 33.1 ± 1.85). As in our prior study (Thakral et al., 2017), the vertex was chosen as the control cTBS site. The vertex was identified on each participant's anatomic image as the location at which the central sulci in each hemisphere met (for other studies employing the same control site, see Bonnici et al., 2018; Hebscher et al., 2019; Ryals et al., 2016; Yazar et al., 2014).

A MagPro X100 Magnetic Stimulator equipped with a Cool-B65 A/P 75-mm coil was used to apply cTBS (Huang et al., 2005). The Brainsight (Rogue Research) neuronavigation system was used to apply the cTBS and allow real-time tracking of the TMS coil relative to physical head and linked anatomic image. Further details on the adopted cTBS approach and Brainsight neuronavigation system on a participant-to-participant basis are contained in the Supplementary Materials. Following application of cTBS, participants were placed into the fMRI scanner. The functional and resting-state scan began ∼5 to 7 min and ∼22 to 25 min following cTBS offset, respectively. fMRI data acquisition was completed within 60 min (i.e., the assumed duration of the effects of cTBS) (Huang et al., 2005). Postscan data collection began ∼60 min following the cTBS offset. Although prior studies indicate that the effects of the current cTBS protocol dissipate within 60 min (Huang et al., 2005), no study has directly examined the timecourse of cTBS over the parietal cortex. We note that an analysis of additional postscan data revealed null effects of TMS (e.g., as reported in the Supplementary Materials, Table S3.2**,** there were no TMS effects in rated plausibility of event, self-rated creativity, and so forth). These null effects suggest that the cTBS effects had dissipated. Importantly, we did replicate our original TMS study where participants verbally generated fewer episodic details during future imagining (with no deficit in a nonepisodic control task) directly following rTMS to the left AG relative to the vertex.

Figure 3.2 *Representative-participant cTBS target identification*



Note. (A) On an individual participant basis, a seed-to-voxel analysis was conducted using the resting-state data from the no-cTBS session (i.e., session 1). A 6-mm sphere (shown in red) in the left anterior hippocampus was centered on a peak voxel previously associated with divergent thinking, episodic simulation, and episodic memory (x = −25, y = −10, z = −19; see fMRI Aquisition and Analysis, Resting-state analysis for details). (B) Whole-brain correlation images were created by using the averaged time series across all voxels comprising the seed and the time series corresponding to each voxel across the brain with Pearson's correlation. The AG cTBS target (shown in red) was selected as the peak coordinate in the left AG demonstrating the greatest resting-state connectivity (i.e., Fisher-transformed correlation, r) and that fell within the left Brodmann area 39 (i.e., the left AG). Resting-state results are overlaid onto a representative participant anatomic image.

Results

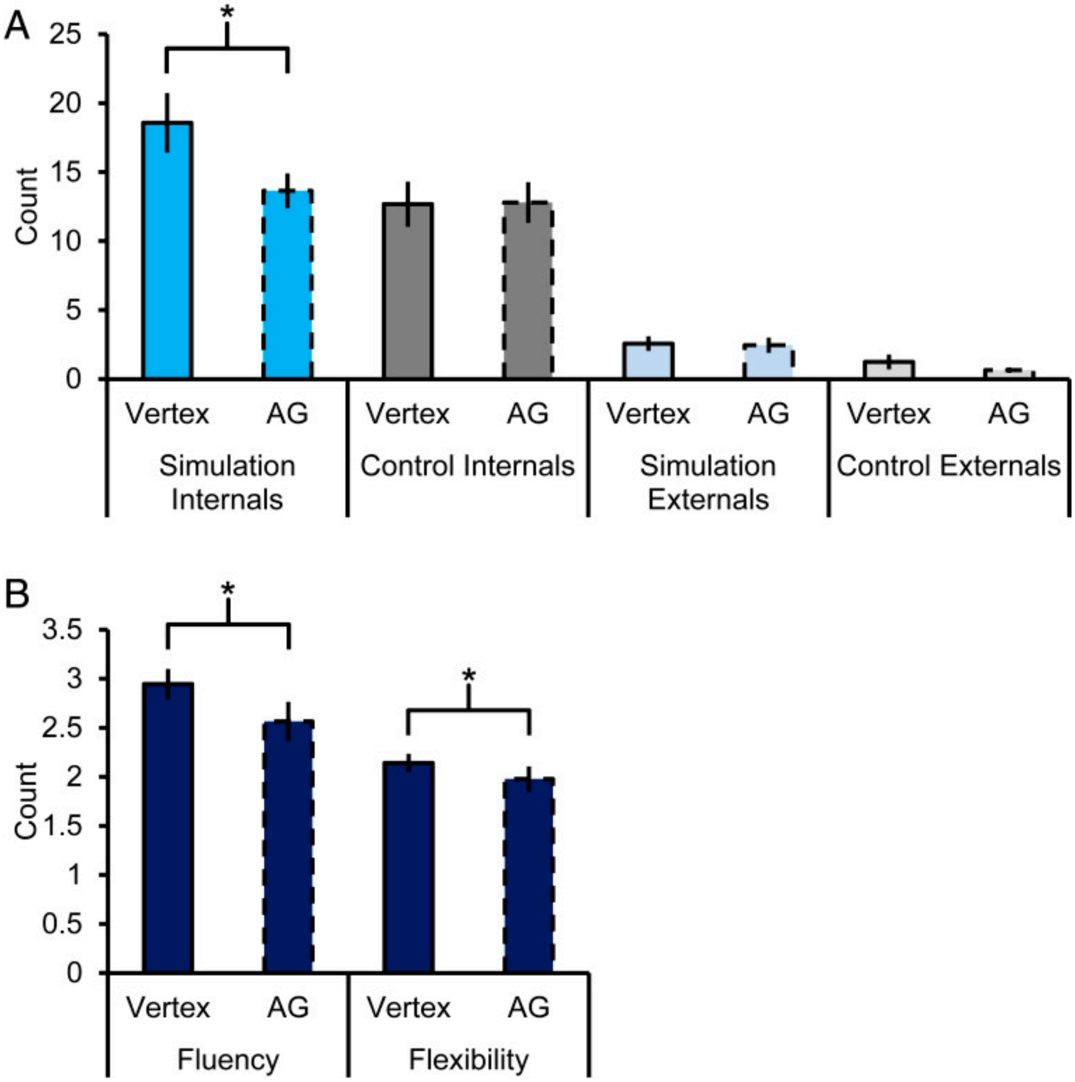
Our primary analyses examined the influence of cTBS to the AG relative to the control site (vertex) (Bonnici et al., 2018; Thakral et al., 2017) on behavioral performance (episodic simulation, divergent thinking, and nonepisodic control), resting-state fMRI connectivity involving the hippocampus, and univariate fMRI effects during task performance in the hippocampus and other brain regions.

TMS Behavioral Results

To replicate our prior findings and serve as a manipulation check for the divergent thinking analysis, we first examined impacts of cTBS on episodic simulation to assess whether the manipulation led to expected decrements in episodic detail production during episodic simulation but not the nonepisodic control task. An ANOVA with factors of cTBS site (vertex and AG), Task (episodic simulation and nonepisodic control), and Detail (internal/episodic and external/nonepisodic) conducted on the generative responses collected during the postscan interview (Fig. 3.3A) revealed a significant three-way interaction [$F(1, 17) = 12.77$, $P = 0.002$, partial $\eta^2 = 0.43$]. The ANOVA also revealed significant main effects of cTBS site, Task, and Detail [Fs$(1, 17) > 10.21$, Ps < 0.005, partial η^2s > 0.38], as well as a cTBS site × Detail interaction [$F(1, 17) = 7.35$, $P = 0.02$, partial $\eta^2 = 0.30$]. The Task × Detail interaction was not significant [$F(1, 17) = 2.12$, $P = 0.16$].

To decompose the significant three-way interaction, two follow-up ANOVAs were conducted with factors cTBS site and Task: one conducted on the internal details (Fig. 3.3A, first four bars) and another on the external details (Fig. 3.3A, last four bars). The ANOVA conducted on the internal details (Fig. 3.3A, first four bars) revealed significant main effects of cTBS site, with more internal details produced following vertex vs. AG cTBS [$F(1, 17) = 13.35$, $P = 0.002$, partial $\eta^2 = 0.44$], and Task, with more details produced for the episodic simulation vs. nonepisodic control task [$F(1, 17) = 6.19$, $P = 0.02$, partial $\eta^2 = 0.27$]. Critically, the cTBS site by Task interaction was significant [$F(1, 17) = 13.28$, $P = 0.002$, partial $\eta^2 = 0.44$]. Follow-up *t* tests revealed that, following cTBS to the AG vs. vertex, participants generated fewer internal details when imagining a future episode [$t(17) = 3.90$, $P = 0.001$, $d = 0.92$] with no analogous decrement in internal detail production for the nonepisodic control task ($t < 1$). To confirm that this decrement was selective to internal/episodic detail production, we conducted a follow-up ANOVA with factors cTBS site and Task conducted on only the external details (Fig. 3.3A, last four bars) and found only a main effect of Task, with more external details produced for the episodic simulation vs. nonepisodic control task [$F(1, 17) = 19.78$, $P < 0.001$, partial $\eta^2 = 0.54$]; all other ANOVA results were nonsignificant [$F\text{s}(1, 17) < 1.78$, $P\text{s} > 0.20$]. Taken together, these findings replicate our prior findings (Thakral et al., 2017) and indicate that hippocampal-targeted cTBS through the AG (vs. vertex) selectively impaired the generation of internal/episodic details during episodic simulation.

Figure 3.3 *TMS-behavioral results*



Note. (A) Mean number of internal and external details for the simulation and control tasks produced following vertex cTBS and left AG cTBS. (B) Mean divergent thinking performance (measured as the total number of appropriate uses generated [fluency] and categories of appropriate uses [flexibility]) following vertex cTBS and left AG cTBS. Error bars denote mean (±1 SE). Asterisks indicate significant results (see TMS Behavioral Results for details).

We then tested for cTBS-related effects on divergent thinking by assessing the effect of cTBS on the generative responses produced for the AUT (i.e., creative uses) in the postscan. Here, we focused on two common metrics of divergent thinking performance: fluency and flexibility (the latter being a more stringent criterion for a use) (Madore et al., 2015, 2019). Following cTBS to the AG vs. vertex, participants generated significantly fewer uses (i.e., were less fluent) (Fig. 3.3B, *Left*) [$t(17) = 3.14$, $P = 0.006$; $d = 0.74$], and these uses fit into significantly fewer distinct and appropriate categories (i.e., were less flexible) (Fig 3.3B, *Right*) [$t(17) = 2.24$, $P = 0.04$, d = 0.53] (for an analysis of other metrics of divergent thinking, see Supplementary Materials). We also conducted analyses on the in-scan and additional postscan ratings to examine task compliance, phenomenological characteristics, and the influence of cTBS (Supplementary Materials, Table S3.1 & S3.2); there were no impacts of cTBS on subjective ratings.

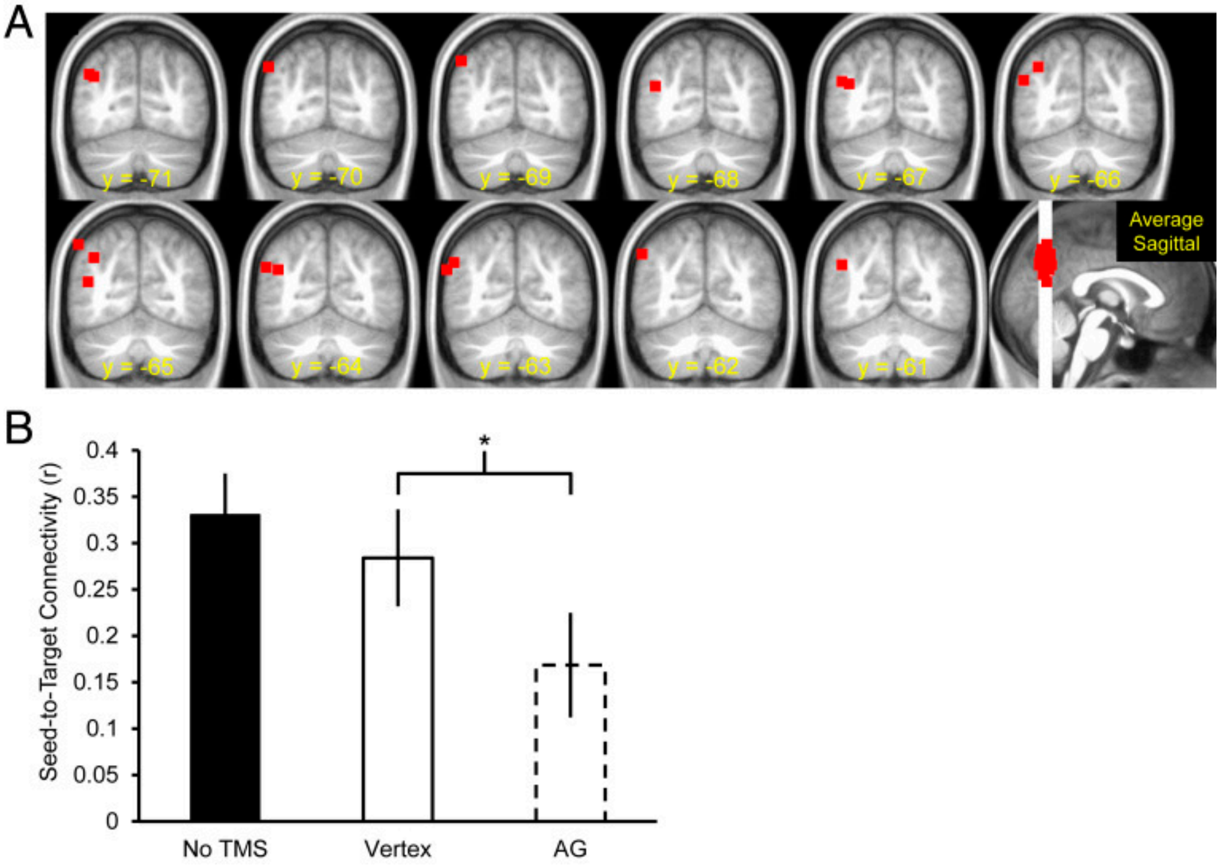
fMRI-TMS Results

Resting-state analyses

Moving from behavioral to fMRI effects of cTBS, we conducted a resting-state analysis to examine whether seed-to-target (i.e., hippocampus-to-AG) connectivity decreased after cTBS to the AG vs. vertex (Fig. 3.4A shows the cTBS targets across the entire sample and Fig. 3.4B shows mean seed-to-target connectivity as a function of the three cTBS sessions). In this analysis, we extracted the correlation value at the AG coordinate stimulated on an individual participant basis as a function of the three cTBS sessions (no-cTBS, vertex, and AG). For each session (no-cTBS, vertex cTBS, and AG cTBS), mean connectivity between the hippocampal seed and AG target was greater than 0 [ts(17) > 2.99, Ps < 0.008, ds > 0.70]. Following cTBS to the AG, there was a significant reduction in connectivity between the AG and the left anterior hippocampal seed vs. cTBS to the vertex [$t(17) = 2.33$, $P = 0.03$, $d = 0.61$]. Seed-to-target connectivity did not differ between the no-cTBS session and cTBS to the vertex ($t < 1$).

We also tested for the specificity of the effect of cTBS on connectivity between the hippocampal seed and AG target site. In this analysis, we examined whether cTBS to the AG relative to the vertex also changed connectivity between the hippocampal seed and two other known resting-state fMRI networks, the frontoparietal control network (FPCN) and the visual attention network (VAN; for full details, see Supplementary Materials). An ANOVA on the correlation values with factors Network (hippocampus-to-FPCN, hippocampus-to-VAN, hippocampus-to-AG) and cTBS site (vertex, AG) revealed main effects of Network and TMS site (Fs > 5.74, Ps > 0.03, partial $\eta^2 > 0.25$), and critically, a significant Network × cTBS site interaction [$F(2, 34) = 4.32$, $P = 0.02$, partial $\eta^2 = 0.20$]. Follow-up pairwise comparisons revealed that connectivity between the hippocampus and FPCN or VAN did not change as a function of cTBS site [ts(17) < 1.40, Ps > 0.18], relative to the significant change in hippocampus-to-AG connectivity reported above. The significant interaction indicates that cTBS to the AG reduced connectivity specifically between the seed (hippocampus) and target (AG), with no detectable changes between the hippocampus and other known resting-state networks (FPCN or VAN).

Figure 3.4 *Target sites for cTBS across individuals and resulting seed-to-target connectivity*



Note. (A) cTBS target sites for each of the 18 participants overlaid on the across-participant mean T1-weighted anatomical image. Each red square denotes the cTBS target for each participant. The coronal slices are spaced every 1 mm with the most posterior (Upper Left) and anterior (Lower Right) corresponding to y = −71 and y = −61, respectively. (B) Group seed-to-target resting-state connectivity as a function of cTBS site. Error bars denote mean (±1 SE) connectivity. Asterisks indicate significant results (see fMRI-TMS Results, Resting-state analyses for details).

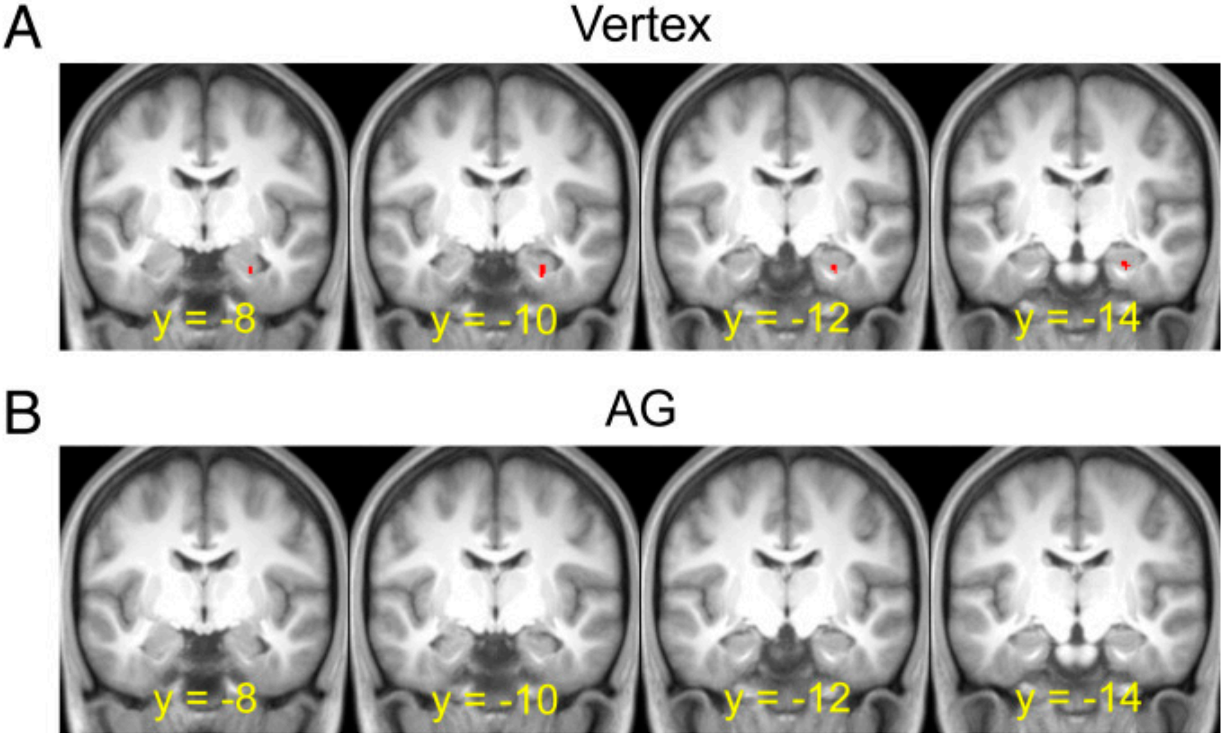
Univariate analyses

The following fMRI analyses were aimed at identifying univariate cTBS effects specific to the episodic simulation and divergent thinking tasks: a neural analog of the observed behavioral deficits in episodic simulation and divergent thinking following cTBS to the AG vs. vertex. To achieve this aim, we implemented an interaction contrast (episodic simulation + divergent thinking > nonepisodic control for the vertex > AG cTBS contrast), which identifies neural regions where task effects common to both episodic simulation and divergent thinking (i.e., episodic simulation + divergent thinking > nonepisodic control) differ as a function of cTBS site (Fig. 3.5). Unless otherwise noted, all results are derived from statistical parameters that survive a significance threshold of $P < 0.05$ corrected for multiple comparisons (see Materials and Methods).

Planned contrasts within the hippocampus

We first tested whether hippocampal cTBS effects could be identified that were common to the episodic simulation and divergent thinking tasks. Following cTBS to the vertex, common activity during episodic simulation and divergent thinking (relative to nonepisodic control) was observed in the hippocampus (peak voxel of $x = 27$, $y = -13$, $z = -24$, peak Z of 3.33, 26 voxels) (Fig. 3.5A). Following cTBS to the AG, there was a reduction of the activity observed vs. cTBS to the vertex (Fig. 3.5B).

Figure 3.5 *fMRI-TMS results: Hippocampus*

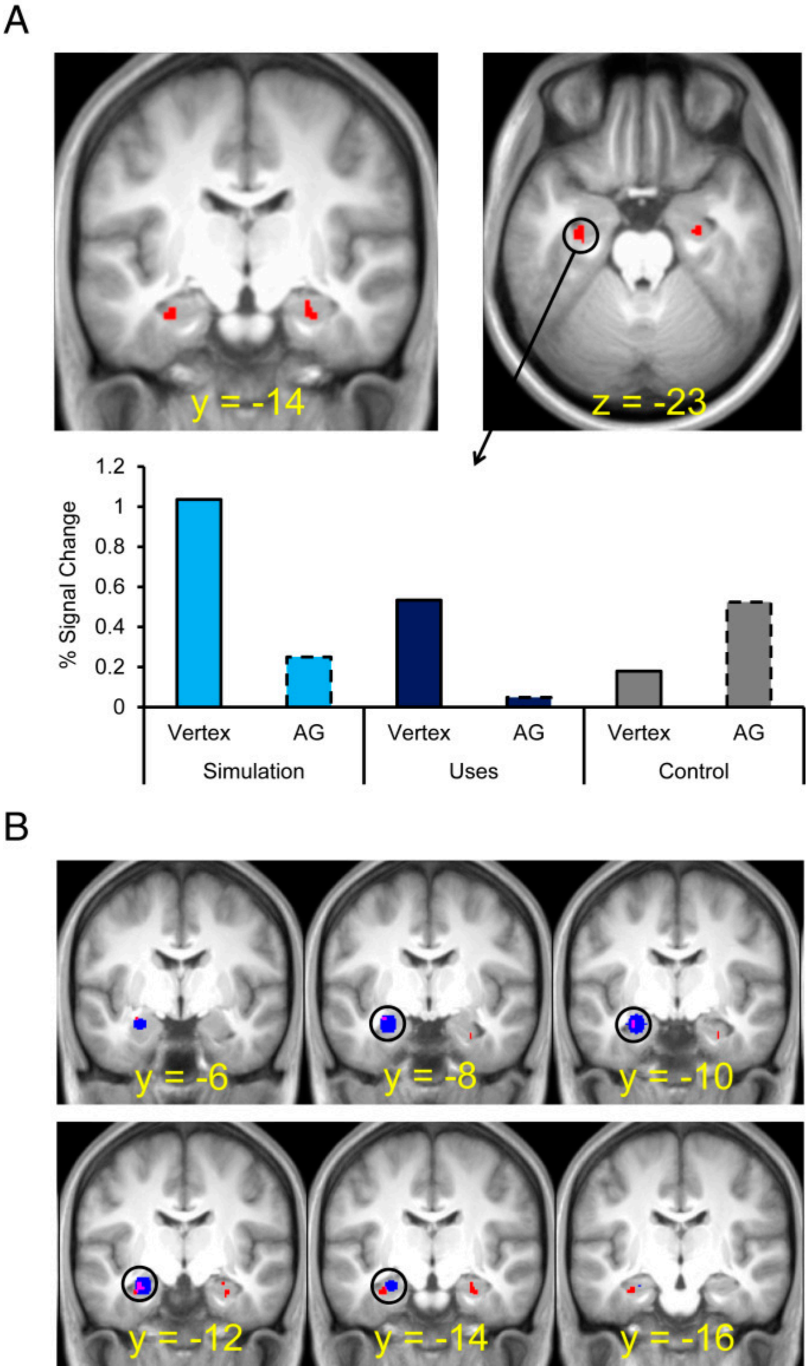


Note. (A) Shown in red are hippocampal regions demonstrating greater activity for the episodic simulation and divergent thinking tasks relative to the nonepisodic control task following cTBS to the vertex. (B) Hippocampal regions demonstrating greater activity for the episodic simulation and divergent thinking tasks relative to the nonepisodic control task following cTBS to the AG. Results are overlaid on the across-participant mean T1-weighted anatomical image.

Critically, we then tested whether hippocampal activity showed an interaction as a function of cTBS site and task (i.e., reduced recruitment for constructing imagined events and generating creative uses following AG cTBS vs. vertex cTBS, with the opposite effect for the control task). The interaction contrast identified two hippocampal clusters, one in each hemisphere, falling primarily in the anterior hippocampus (Fig. 3.6A, *Upper*, and Table 3.1). To further characterize the results, we illustrate the parameter estimates for each cTBS site and task (Fig. 3.6A, *Lower*) extracted from the left hippocampus. These estimates parallel the behavioral cTBS deficit and reveal cTBS univariate effects for episodic simulation and divergent thinking but not the nonepisodic control.

Of particular interest, the interaction effect identified in the left anterior hippocampus overlapped the hippocampal seed targeted via the seed-to-target resting-state analysis that was identified in previous metaanalyses on divergent thinking (Wu et al., 2015) and episodic memory and simulation (Benoit & Schacter, 2015) (Fig. 3.6B). These findings suggest that cTBS to the AG identified on an individual participant basis not only reduced functional connectivity to the hippocampus during rest (Fig. 3.4B), but also reduced neural activity during tasks that have been hypothesized to engage the hippocampus (i.e., episodic simulation and divergent thinking).

Figure 3.6 *fMRI-TMS results: Hippocampus*



Note. (A) Shown in red are hippocampal regions demonstrating a cTBS site by task interaction (i.e., reduced recruitment for constructing imagined events and generating creative uses following AG cTBS compared with cTBS to the vertex with the opposite effect for the control task). The chart depicts percent signal change (extracted from the region's peak voxel) for each task and cTBS site. Note that error bars are not plotted as a result of potential noise, and significance tests were not run on these data. (B) The fMRI-cTBS effect identified in the hippocampus (shown in red) overlapped the hippocampal seed region targeted with cTBS (shown in blue; i.e., the coordinate employed in the seed-to-voxel analysis to identify the cTBS target region in the left AG). Overlap is shown in magenta. Results are overlaid on the across-participant mean T1-weighted anatomical image.

To further link the key cTBS-related behavioral and hippocampal results, the behavioral scores were entered as modulators of interest during the construction phase of imagined events, divergent thinking, and control tasks (for similar procedures, see Madore, Szpunar, et al., 2016). For the behavioral index, episodic/internal details on the imagine task, fluency scores on the divergent thinking task, and internal details on the control task were used. Critically, cTBS-related reductions in hippocampal activity were observed during the construction of imagined events and divergent thinking over the control task following cTBS to the vertex vs. AG (peak voxel of $x = -22$, $y = -10$, $z = -22$; peak Z of 2.98; these effects were observed at an uncorrected two-tailed threshold of $P < 0.005$; for full details, see Supplementary Materials). Akin to the main univariate analysis reported above, this modulatory effect overlapped the hippocampal seed targeted via the seed-to-target resting-state analysis. The parametric modulation analysis indicates that the key cTBS-related behavioral effects (reduced episodic details and fewer creative uses following cTBS to the vertex vs. AG) modulated the key cTBS-related neural effect (i.e., reduced hippocampal activity during episodic simulation and divergent thinking following cTBS to the vertex vs. AG).

Whole-brain analyses

Along with impacts of cTBS on hippocampal connectivity and activity, we probed further neural differences (shown in Fig. 3.7) with an episodic simulation + divergent thinking > nonepisodic control contrast as a function of each cTBS site across the whole-brain. After cTBS to either site (Fig. 3.7A and B, for vertex or AG, respectively), there was common recruitment during both episodic simulation and divergent thinking in core network regions (e.g., Benoit & Schacter, 2015; Wu et al., 2015). Critically, participants exhibited significantly reduced activation in several core network regions following cTBS to AG vs. vertex for episodic simulation and divergent thinking relative to the nonepisodic control (Fig. 3.8), which included the ventromedial prefrontal cortex, bilateral lateral temporal cortex (i.e., right and left inferior and middle temporal gyri/sulci), and posterior cingulate/retrosplenial cortex, among others (for a full list, see Table 3.1). Common cTBS univariate effects were also observed in regions comprising the frontoparietal control network, such as the inferior frontal gyrus, regions previously associated with episodic simulation and divergent thinking (e.g., Gerlach et al., 2014; Madore et al., 2019; Spreng et al., 2010), and thought to support cognitive control processes required for the recombination of disparate episodic details. Illustrated are the parameter estimates extracted from two representative regions, the lateral temporal cortex and medial prefrontal cortex. In each region, a cTBS effect (i.e., vertex > AG) was present for both the episodic simulation and divergent thinking tasks but not the nonepisodic control.[3]

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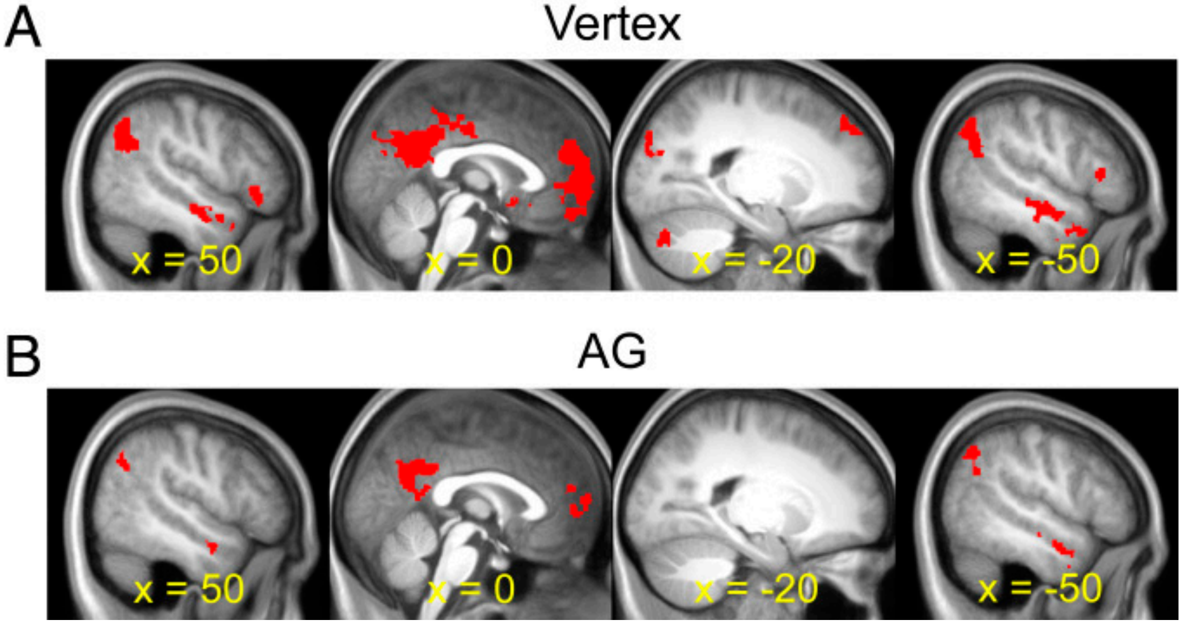
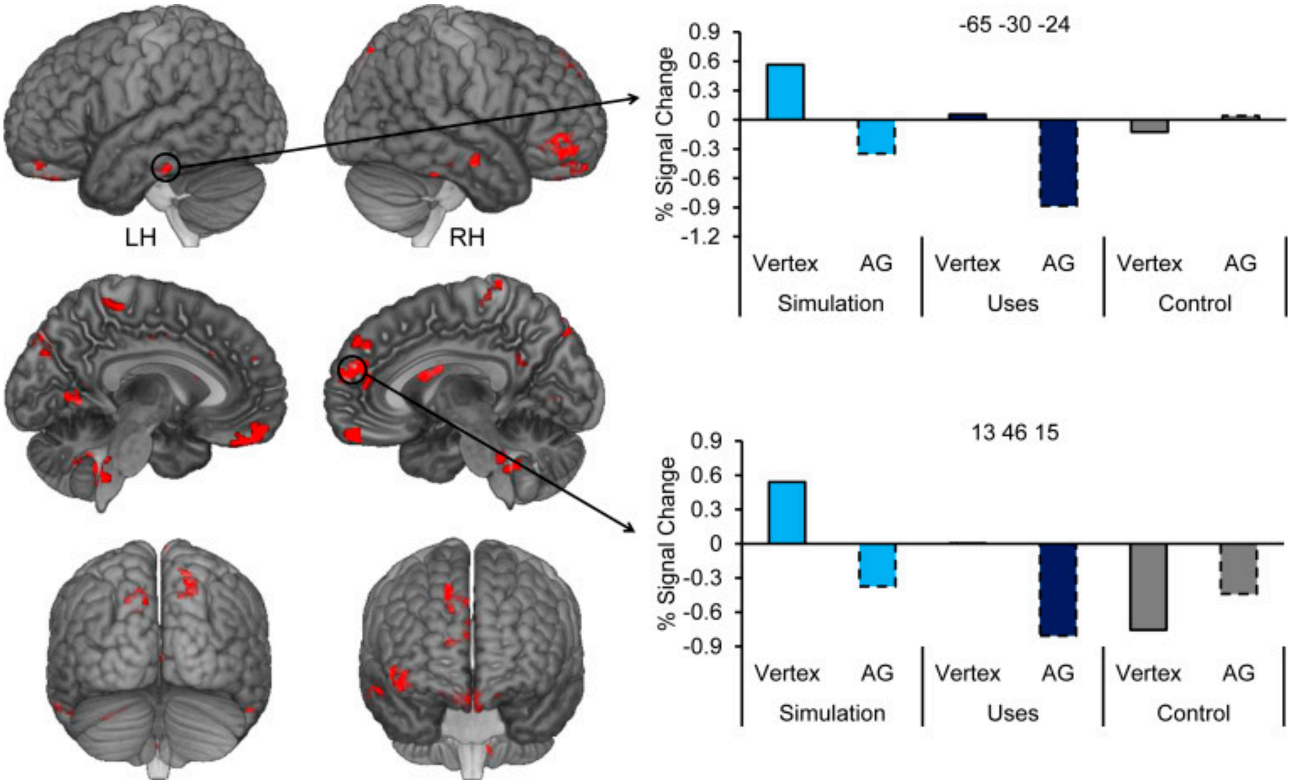
[3] Note that the interaction contrast does not ensure that the magnitude of the cTBS effects as a function of the two tasks of interests (episodic simulation and divergent thinking) are statistically equivalent in magnitude. The interaction contrast only indicates that the parameter estimates associated with neural activity following cTBS to the vertex for both episodic simulation and divergent thinking are numerically greater than the respective task conditions following cTBS to the AG (and the opposite for the non-episodic control). To ensure a statistically common cTBS effect, we employed the inter- action contrast restricted to only the episodic simulation and divergent thinking as a function of cTBS site as an exclusive mask. That is, we statistically removed all voxels at the lenient threshold of $P < 0.05$ where the magnitude of the cTBS effect for episodic simulation differed from divergent thinking (and vice versa). Critically, the same peak clusters were identified both at the whole-brain level and in the hippocampus. The analysis confirms the reported commonality of the cTBS effect across the two tasks.

Figure 3.7 *fMRI-TMS results: Whole-brain*



Note. (A) Shown in red are whole-brain regions demonstrating greater activity for the episodic simulation and divergent thinking tasks relative to the nonepisodic control task following cTBS to the vertex. (B) Whole-brain regions demonstrating greater activity for the episodic simulation and divergent thinking tasks relative to the nonepisodic control task following cTBS to the AG. Results are overlaid on the across-participant mean T1-weighted anatomical image.

Figure 3.8 *fMRI-TMS results: Whole-brain.*



Note. Shown in red are whole-brain regions demonstrating a cTBS site by task interaction (i.e., reduced recruitment for constructing imagined events and generating creative uses following cTBS to the left AG compared with cTBS to the vertex with the opposite effect for the control task). The charts depict percent signal change extracted from peak voxels within two representative clusters within the left lateral temporal cortex (x = −65, y = −30, z = −24) and medial prefrontal cortex (x = 13, y = 46, z = 15) for each task and cTBS site. Note that error bars are not plotted as a result of potential noise, and significance tests were not run on these data. Results are projected onto a cortical surface using the skull-stripped template of MRIcroGL (see Rorden et al., 2007).

Table 3.1 *Loci of fMRI-TMS effects*

	MNI coordinates			Peak *Z*	Number of above-threshold voxels	Region
	X	*y*	*z*			
Hippocampus	−31	−17	−22	3.99	36	Left hippocampus
	27	−13	−22	3.97	24	Right hippocampus
Whole brain	42	50	−12	5.39	243	Right inferior frontal gyrus
	−27	7	17	5.30	111	Left frontal operculum
	42	−7	41	3.65	228	Right middle frontal gyrus
	5	55	−24	4.83	372	Right ventromedial prefrontal cortex
	−12	51	−16			Left ventromedial prefrontal cortex
	13	0	24	4.59	130	Right caudate nucleus
	−5	−42	−50	4.52	231	Left cerebellum
	5	−39	−38			Right cerebellum
	−21	−78	−33	4.39	175	Left cerebellum
	22	34	−7	4.33	162	Right orbital gyrus
	56	−22	−19	4.33	227	Right inferior temporal sulcus
	59	−13	−17			Right middle temporal gyrus
	47	−24	−27			Right inferior temporal gyrus
	13	−49	27	4.31	226	Right posterior cingulate/retrosplenial cortex
	44	−53	25			Right angular gyrus
	−9	−41	63	4.28	110	Left paracentral lobule
	3	−30	64			Right paracentral lobule
	−17	−52	−21	4.27	177	Left cerebellum

Table 3.1 continued

	MNI coordinates			Peak *Z*	Number of above-threshold voxels	Region
	X	*y*	*z*			
Whole brain	18	−76	54	4.21	98	Right superior parietal lobule
	17	−85	42			Right superior occipital gyrus
	37	4	20	4.19	166	Right frontal operculum
	−65	−30	−24	4.19	189	Left inferior temporal gyrus
	−55	−20	−17			Left middle temporal gyrus
	−10	−80	29	3.99	172	Left superior occipital gyrus
	13	46	15	3.94	256	Right dorsomedial prefrontal cortex
	12	65	12			Right anterior prefrontal cortex
	10	44	39	3.77	158	Right superior frontal gyrus
	−2	−68	5	3.17	96	Left extrastriate cortex

Note. MNI, Montreal Neurological Institute. Coordinates for cluster subpeaks that lie in distinct cortical regions are listed directly below relevant peak cluster.

Discussion

We tested the causal role played by episodic memory retrieval in future imagining and creative thinking by using cTBS to the parietal cortex (left AG) and targeting the hippocampus, two brain regions involved in episodic memory. The left AG region targeted for cTBS was identified on an individual participant basis employing a baseline (no-cTBS) resting-state functional connectivity analysis with a left anterior hippocampal seed region previously associated with episodic memory, episodic simulation, and divergent creative thinking. Replicating our prior findings, compared with cTBS to the vertex, cTBS to the AG region reduced the number of episodic details produced for the simulation task (Thakral et al., 2017). Critically, cTBS to the AG relative to the vertex also reduced the number of creative uses produced for the divergent thinking task. In contrast, performance in the nonepisodic control task did not statistically differ as a function of cTBS site. Analysis of the fMRI data revealed a selective and simultaneous reduction in hippocampal activity during episodic simulation and divergent thinking following cTBS to the AG vs. vertex but not during the nonepisodic control task (i.e., a task that engages semantic retrieval and imagery but requires little divergent thinking or episodic processing). This hippocampal cTBS univariate effect overlapped the region targeted via the resting-state connectivity analysis. In addition, resting-state analyses revealed that, following cTBS to the AG vs. vertex, there was a significant reduction in functional connectivity between the left AG and hippocampus, suggesting that reduced communication between these two core network regions led to reduced ability to think creatively and to imagine an episodic future event. Taken together, our findings provide evidence that hippocampal-targeted cTBS can specifically modulate episodic simulation and divergent thinking, and suggest that the hippocampus supports a common and critical process during these cognitive functions. Further support for a brain–behavior link was identified via the parametric modulation analysis, which revealed that cTBS-related behavioral differences in episodic simulation and divergent thinking modulated cTBS-related hippocampal activity. This latter finding should be taken as preliminary, however, as it only emerged at an uncorrected statistical threshold.

The present findings have implications for our understanding of the cognitive neuroscience of creativity. The dominant view is that creativity, specifically divergent thinking is largely, if not completely, supported by semantic memory (e.g., Mednick, 1962; Smith et al., 1995; Welch, 1946). This view has been supported by neural evidence indicating that regions associated with semantic control and retrieval are recruited during divergent thinking tasks (e.g., Beaty et al., 2020; Fink et al., 2015; Sun et al., 2016; for review, see Wu et al., 2015). Although some evidence suggests that episodic memory and divergent thinking are supported by common cognitive and neural underpinnings, such evidence has its weaknesses (see *Introduction*). The current causal findings add to the small but growing body of studies indicating that the dominant view needs revision to account for the role of episodic retrieval in divergent creative thinking. Our findings are also consistent with previous literature indicating that the role of episodic retrieval in divergent thinking is best captured by quantity but not quality measures. For example, and akin to the present cTBS findings, the ESI primarily impacts fluency and flexibility metrics of divergent thinking but not creativity ratings (Madore et al., 2015, 2019; Madore, Jing, et al., 2016). Taken together, the present and previous findings suggest that episodic retrieval can be considered a component process of divergent thinking, likely impacting the production of creative output, and provide support for the idea that the hippocampus, and core network more broadly, contributes to performance on generative tasks that nominally involve retrieval and reconstruction of episodic information for completion (Moscovitch et al., 2016; Schacter et al., 2012; for related perspectives, see Richmond & Zacks, 2017; Romero & Moscovitch, 2012; Rubin et al., 2014).

There are several limitations of the present study that deserve mention. First, we failed to identify any cTBS-related univariate effects as a function of episodic simulation and divergent thinking in the region directly stimulated, the left AG. Such a finding would suggest that cTBS has no effect on underlying neural activity at the site of application, and therefore call into question our prior claim that the left AG plays a necessary role during episodic memory and simulation (Thakral et al., 2017; see also Bonnici et al., 2018). However, several methodological differences between the present study and our previous one (Thakral et al., 2017) could explain the present null finding. First, the present study utilized a different TMS protocol (i.e., a cTBS protocol vs. the prior repetitive 1-Hz stimulation protocol), and the cTBS target was identified on an individual participant basis and varied in spatial location across participants (e.g., spanning 10 mm in the *y* dimension; in our prior study, the target site was identical across participants) (Fig. 3.4A). The relatively large spatial distribution of the cTBS target site may have limited the ability to identify a common across-participant univariate cTBS effect. Relevant to this point, the cTBS seed location (i.e., left anterior hippocampus) was held constant across participants, and was also a region where univariate cTBS effects were observed (Fig. 3.6B). These findings suggest that there may be a relationship between the ability to detect TMS-related task univariate effects and the variability of the target site across participants. To test this interpretation, we extracted univariate activity for each of the three tasks from the individualized target AG location as a function of the cTBS sites (both using a single 1.7-mm voxel as well as a 6-mm sphere). There were numeric decreases in univariate activity for both the simulation and divergent thinking tasks, with the reverse for the control task, following AG cTBS relative to vertex cTBS, but these differences were not significant (i.e., there was no significant reduction in univariate activity following AG cTBS relative to vertex cTBS for both the simulation and divergent thinking tasks [*t*s(17) < 1.08, *P* = 0.30]). Most important, cTBS did result in a significant reduction in seed-to-target connectivity, which provides evidence that cTBS had an effect at the sites of interest (i.e., left AG and hippocampus).

A second limitation stems from the fact that the resting-state scans were acquired after the functional/task runs (see also Madore et al., 2019; Madore, Szpunar, et al., 2016). Because cTBS affected neural activity during the task runs, it is unclear whether the change in seed-to-target connectivity was a result of cTBS or the change in task performance/neural activity as a result of cTBS (cf. Grigg & Grady, 2010). A final limitation stems from the lack of a cTBS effect on subjective vividness ratings. We have provided recent evidence that the hippocampus (relative to other core network regions) plays a privileged role in supporting the subjective experience of episodic content via self-rated vividness (Thakral, Madore, Addis, et al., 2020; Thakral, Madore, & Schacter, 2020). Although the present null finding casts doubt on the link between hippocampal activity and vividness that was based on correlational fMRI data, any null effect should be treated with caution as it can be accounted for in any number of ways (e.g., low power). These limitations should be addressed in future work.

The present study employed a cTBS protocol that was assumed to be inhibitory and therefore produce a decrement in behavioral performance. This assumption is supported by prior work showing that cTBS reduces cortical excitability (Huang et al., 2005) as well as univariate fMRI activity (Hubl et al., 2008). In addition, cTBS disrupts behavioral performance in autobiographical memory tasks (Bonnici et al., 2018; Hebscher et al., 2019). The present and earlier findings indicating that cTBS can be used to produce inhibitory behavioral effects are inconsistent with some prior findings showing that application of cTBS enhances memory performance (Hermiller et al., 2019; Tambini et al., 2018). One difference between the present observations and prior findings of enhancement is a difference in the control cTBS condition. Here, the control condition was cTBS to the vertex [akin to previous studies also reporting decreases in behavioral performance (Bonnici et al., 2018; Hebscher et al., 2019)]. In the studies that have reported an increase in performance from cTBS, the control condition was either TMS to the primary somatosensory cortex (Tambini et al., 2018) or sham TMS (Hermiller et al., 2019). An additional possibility raised by Hebscher and Voss (2020) is that studies reporting behavioral increases from cTBS used complex visual memoranda with laboratory-based episodic memory paradigms, which may depend heavily on hippocampal retrieval processes (i.e., pattern completion) with relatively little necessary involvement of the AG. Thus, if stimulation were to disrupt local processing by the AG yet enhance downstream processing by the hippocampus, the disruptive effect of stimulation on episodic processing in the present study could reflect disruption of AG involvement in generating the retrieval cues that are presumably used by the hippocampus to support performance. In contrast, in previous studies finding behavioral enhancement, such cues were provided by the visual display and so beneficial effects of stimulation on the hippocampal contribution could be observed. Additional research is needed to clarify this issue.

An important point about the present pattern of results is that the effect of cTBS on neural activity was not specific to the hippocampus. As illustrated in Fig. 3.8, effects of cTBS on episodic simulation and divergent thinking extended to other core network regions, such as the medial prefrontal cortex, as well as noncore regions, such as the inferior frontal gyrus, regions also associated with both episodic simulation and divergent thinking. Here, we highlight the findings pertaining to the hippocampus given strong theoretical and experimental work demonstrating a link between this region and divergent thinking and episodic simulation (e.g., Benoit & Schacter, 2015; Moscovitch et al., 2016; Schacter & Addis, 2020; Wu et al., 2015). An important avenue for future work will be to combine TMS with analytic approaches examining the direction of informational flow between regions such as effective connectivity (cf., Campbell et al., 2018; see also Gerlach et al., 2014; Spreng et al., 2010). Finally, our analytical approach was aimed at identifying an interaction between cTBS site and task, in part to identify neural regions that tracked any cTBS behavioral effects. One drawback of this procedure is that the regions identified might be differentially sensitive to the episodic simulation and divergent thinking tasks themselves (e.g., in the hippocampus, although the average neural activity between simulation and divergent thinking was greater than in the control task following vertex cTBS, the magnitude of activity was numerically greater for simulation than divergent thinking) (Fig. 3.6A). This pattern of effects would suggest that the process or processes mediated by the hippocampus, although common, are engaged to a greater extent during simulation relative to divergent thinking (cf., Beaty et al., 2018).

In conclusion, the present findings provide evidence indicating that episodic retrieval plays a causal role in supporting episodic simulation and divergent thinking through common hippocampal-mediated processes. It will be important for future studies to specify the precise hippocampal process or processes shared across episodic simulation and divergent thinking. In a prior study, for example, we employed multivoxel pattern analysis and demonstrated that the hippocampus supports the reinstatement of episode-specific information from memory during simulation (Thakral, Madore, Addis, et al., 2020). Such reinstatement may also support the generation of creative output during divergent thinking. Combining multivoxel pattern analysis with TMS may be a fruitful approach for specifying the hippocampal processes common not only to episodic simulation and divergent thinking, but also to other functions that benefit from episodic retrieval.

Chapter 5: General Discussion

Evaluating the contribution of episodic retrieval processes to other adaptive functions, such as episodic future thinking and divergent creative thinking, has been a central goal in recent research aimed at understanding the structure and function of episodic memory. The three studies in the present dissertation each take a different approach to expand upon this broad goal.

In Paper 1, we demonstrated that trait narcissistic grandiosity is associated with a tendency to remember and imagine positive events with heightened subjective detail compared to negative events. In Paper 2, we evaluated the neural correlates of heightened spatial detail in episodic retrieval compared to future thinking. We found that common activity in the precuneus underlies spatial detail about both locations and people across tasks, while a distinct set of regions supports the subjective experience of spatial location detail and spatial detail about people during retrieval but not future thinking. Paper 3 tested the causal role of hippocampal brain networks that support episodic simulation in divergent creative thinking by disrupting these networks using TMS. We found that TMS to our target region reduced performance on episodic simulation and divergent thinking tasks and led to a parallel reduction in hippocampal activity during these tasks, but not a non-episodic control. Together, these results bolster our understanding of the parallels and dissimilarities between episodic retrieval, future thinking, and divergent creative thinking, providing insight into the adaptive functions of a constructive memory system.

Theoretical Implications

The results discussed in the present dissertation are generally in line with the *constructive episodic simulation hypothesis,* which states that details stored in episodic memory are flexibly recombined into novel imagined events during episodic future thinking (Schacter & Addis, 2007, 2020). This same flexible recombination mechanism can be leveraged for other functions, like divergent creative thinking.

In Paper 1, the demonstration of parallel tendencies towards a greater phenomenological experience in both past and future for positive events is consistent with constructive episodic simulation. If participants are sampling from details stored in episodic memory to construct novel future events, biases in thinking about the past should extend to thinking about the future. While this flexible recombination mechanism is considered adaptive, as it allows for dynamic evaluation of possible futures in the face of changing environmental challenges, it remains an open question whether the results of Paper 1 demonstrate adaptive or maladaptive patterns. The general population shows a positivity memory bias, or a tendency to recollect positive information, across a variety of measures (see Adler & Pansky, 2020 for review). These positivity biases benefit psychological well-being and healthy coping, as simulating detailed positive events is an effective tool for emotion regulation (Jing et al., 2016), Episodic simulation can also be used as a tool for self-enhancement, as one constructs a coherent life narrative about their personal growth (see Wilson & Ross, 2003 for review). However, too much self-enhancement is maladaptive by contributing to an unrealistic sense of self, which could hinder one’s ability to generate an adaptive simulation that accurately reflects the environment. Therefore, the adaptiveness of constructive episodic simulation may rest in part on the accuracy of the simulation to the environment at hand.

Paper 2 adds to our understanding of constructive episodic simulation by characterizing the neural correlates of behavioral differences that underlie a retrieved memory – higher in spatial detail – compared to a simulated future event. Imagining future events requires increased constructive demands associated with the flexible recombination of details, compared to retrieving past events, which does not require flexible recombination. A substantial part of these heightened constructive demands is due to instantiating a spatial context (Wiebels et al., 2020), so this difference in spatial detail between tasks is intricately related to differences in recombination. Moreover, we found that the background connectivity dynamics did not significantly differ between episodic retrieval and future thinking, demonstrating additional parallels between these tasks, even in the face of phenomenological differences. It is important to note that these tasks, while both relying on constructive episodic processes, are not identical. Remembering a past event does not require recombining details into a novel representation and is more constrained than the vast possibilities one could simulate about the future, while imagining future events requires drawing upon semantic knowledge or event schemas to a greater extent to scaffold an event (e.g., Irish et al., 2012). The results of Paper 2 can be interpreted in this context: the higher fidelity of a preexisting memory representation may lead to a boosted signal in the precuneus, a region that has previously been shown to track vividness judgments (Richter et al., 2016) and is broadly thought to integrate an egocentric visual perspective with vivid mental imagery (Ritchey & Cooper, 2020). Moreover, the finding that some nonoverlapping regions are tracking spatial detail about people and locations supports our understanding of a constructive memory system, in which details are stored separately and combined at the time of retrieval or recombined while creating a novel future scenario.

Finally, Paper 3 tests for a causal role of episodic processes in both future simulation and divergent creative thinking. The hippocampus, to which our disruptive TMS was targeted, is considered a site vital for flexible recombination. Greater hippocampal activity during future thinking is often interpreted as reflecting the greater recombination demands of future thinking than episodic retrieval (Addis et al., 2010; Addis & Schacter, 2012). In line with the constructive episodic simulation hypothesis, the disruptions in both episodic future thinking and divergent creative thinking in the present work occurs due to a hindrance of the ability to recombine details flexibly to aid in these retrieval and recombination processes, as demonstrated by the impaired behavior on both tasks and corresponding reduction in connectivity. More broadly, these results support the contribution of episodic memory to creative thought. While dominant accounts of creativity emphasized the association of knowledge subserved by semantic memory (Mednick, 1962; Mumford et al., 2012; Simonton, 2011; Welch, 1946), more recent work has highlighted the role of episodic memory. Divergent thinking performance is boosted by an episodic specificity induction (Madore, Jing, & Schacter., 2016; Madore et al., 2019), and common core network regions support episodic retrieval, future thinking, and divergent thinking (Beaty et al., 2018). Goal-directed episodic memory processes are thought to contribute to divergent thinking by supporting the retrieval of episodic details and construction of mental imagery that enable people to generate creative ideas (see Benedek et al., 2023 for review). Paper 3 underscores the necessary contribution of episodic memory to divergent thinking by demonstrating a causal relationship between disrupted hippocampal activity and performance on both episodic simulation and divergent thinking tasks.

Overall Limitations and Future Directions

While these papers are informative, it is important to consider their limitations. Paper 1 draws upon clinical theory about narcissistic personality, though we conceptualize narcissism as continuous and composed of trait measures (grandiosity and vulnerability). It would be of interest to evaluate the self-bolstering tendencies in episodic retrieval and future thinking in a clinical sample of people with Narcissistic Personality Disorder, as the present findings only generalize to the concept of pathological narcissism more broadly. Additionally, we suspect that one possible mechanism through which grandiosity may be maintained is through the repeated simulation of positive future events, as repeated simulation of emotional events has been shown to increase the perceived plausibility that those events could happen (Szpunar & Schacter, 2013). This could in turn lead to a larger discrepancy between one's simulated future and reality, thus contributing to narcissistic injury. It would be useful to empirically test this prediction in two stages. First, one could experimentally manipulate the repeated simulation of near-future events in people high in grandiosity, then, following the event, assess their evaluation of how the event actually occurred. Second, it would be useful to know whether people high in grandiosity are naturally engaging in this behavior outside of the lab, so employing an ecological momentary assessment design to sample the content of their thoughts over time and state fluctuations may be of value.

Both Paper 1 and Paper 2 rely on subjective ratings as a measure of phenomenology across episodic retrieval and future simulation. The subjective nature of these constructs makes them potentially susceptible to bias. For example, in Paper 1, we cannot easily disentangle whether participants higher in grandiosity are displaying a bias in their reports that positive events are more vivid, easy, and plausible, or whether they simply live more positive lives. In Study 2, the subjective ratings are central to our hypotheses, though it's important to consider how making these subjective judgments could be changing the nature of the recollections and imagined future events by biasing internal attention to spatial detail. Paper 3 also incorporated subjective ratings of vividness, as we found no impact of hippocampally-targeted TMS on vividness ratings, which contrasts previous findings that the hippocampus tracks subjective vividness (Thakral, Madore, & Schacter, 2020). It is not clear whether this null effect arose from low power, or whether it accurately reflects that correlational evidence from fMRI is providing an incomplete understanding of the relationship between neural activity and subjective phenomenology, which also has implications for the interpretation of Paper 2. Future work, perhaps using TMS to tease apart the causal roles of these regions in subjective experience, is warranted to elucidate these alternatives.

Finally, while the present dissertation has focused on the contributions of episodic memory processes to future thinking and divergent creative thinking, itis also important to consider the impact of semantic memory. Early perspectives on these two types of memory characterized them as distinct systems (Tulving, 1972), though recent accounts citing overlap in clinical and fMRI work take the perspective that episodic and semantic memory exist on a continuum (see Renoult et al., 2019 for review). Some types of generated content fall in between episodic and semantic categories; for example, one may generate a semantic simulation when preparing for a job interview and envisioning the future direction of the company (see Szpunar, Spreng, & Schacter, 2014 for a discussion of types of future thinking along this gradient). Semantic knowledge can be used as a scaffold in which to couch episodic memory (e.g. Irish et al., 2012). The implications of this perspective warrant exploration in the present work. This semantic scaffold is particularly important for future thinking: while patients with semantic dementia experience an impaired ability to think about the future, their ability to remember past events is relatively spared (Irish et al., 2012). Paper 2 sought to characterize greater subjective detail during memory than future thinking, though there are some notable subjective measures greater during future thinking than episodic retrieval. For example, D'Argembeau and van der Linden (2006) found that future events were rated as more personally important and more positive than past events. This could be due to the increased semantic reliance of future, compared to past, events: such a semantic scaffold could include aspects of one's self-concept and identity broadly, upon which episodic details are flexibly incorporated (D'Argembeau et al., 2012). These predictions could be tested using a similar approach to that employed in Paper 2. This episodic-semantic gradient also has important implications for Paper 3, as there are semantic contributions to creative thought. Broadly, these include retrieving and linking concepts: in the AUT, one must understand the concept of a *brick* to determine that it can be used a doorstop or a paperweight (Benedek et al., 2023). Future work should seek to understand the relative contributions of both semantic and episodic memory to different creative tasks, and neurostimulation as in Paper 3 provides an avenue through which this may be explored further.

Conclusions

The present dissertation investigated the cognitive and neural underpinnings of constructive simulation. In Paper 1, we demonstrated a self-enhancing tendency in narcissistic grandiosity in both past and future thinking. In Paper 2, we probed the neural basis of subjective differences between episodic retrieval and future thinking, identifying posterior medial and oculomotor regions that track these differences. In Paper 3, we demonstrated the role of episodic processes in both simulation and divergent creative thinking. Overall, this work may have important implications in clinical and cognitive domains, demonstrating the breadth of impact of constructive episodic simulation.

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Appendix

Paper 1 Supplementary Materials

Table S1.1 *Demographic Table*

	Study 1 (*N* = 112)	Replication (*N* = 169)
	M (*SD*)	*M* (*SD*)
Age (years)	22.36 (2.69)	25.49 (2.66)
	n (%)	*n* (%)
Gender		
Female	65 (58.04)	83 (49.11)
Male	44 (39.29)	83 (49.11)
Non-Binary/genderqueer	3 (2.68)	3 (1.78)
Race		
White	67 (59.82)	109 (64.50)
Asian	23 (20.54)	12 (7.10)
Black or African American	8 (7.14)	28 (16.56)
Not Listed	4 (3.57)	9 (5.33)
More Than One Race	0 (0.00)	8 (4.73)
Native Hawaiian/Pacific Islander	0 (0.00)	1(<1.00)
Employment Status		
Student	72 (64.29)	18 (10.65)
Employed Full Time	19 (16.96)	102 (60.36)
Employed Part Time	14 (12.50)	24 (14.20)
Unemployed; Looking for Work	5 (4.46)	18 (10.65)
Unemployed; Not Looking for Work	2 (1.79)	23(13.61)
Stay-at-home	0 (0.00)	4 (2.37)

Table S1.2 *Study 1 Linear Mixed Effects Model Output for Objective Detail Analyses*

	Internal Details				External Details			
Predictors	β	95% CI	p	p_{fdr}	β	95% CI	p	p_{fdr}
(Intercept)	95.21	70.10 – 120.32	**<.001**	**<.001**	34.26	18.03 – 50.50	**<.001**	**<.001**
Grandiosity	-0.39	-0.59 – -0.18	**<.001**	**<.001**	-0.03	-0.16 – 0.10	.684	.684
Valence (pos)	-13.29	-30.81 – 4.22	.137	.274	3.38	-12.00 – 18.75	.667	.667
Task (retrieval)	15.04	-2.31 – 32.39	.089	.141	-11.43	-26.64 – 3.77	.140	.141
Grandiosity x Valence	0.07	-0.07 – 0.21	.332	.665	-0.01	-0.14 – 0.11	.831	.831
Grandiosity x Task	-0.05	-0.19 – 0.10	.524	.535	0.04	-0.09 – 0.16	.535	.535
Valence x Task	13.53	-11.00 – 38.07	.279	.559	-1.39	-22.89 – 20.12	.899	.899
Grandiosity x Valence x Task	-0.07	-0.27 – 0.14	.525	.936	-0.01	-0.18 – 0.17	.936	.936
Random Effects								
σ^2	595.98				457.90			
τ_{00}	631.17 $_{\text{subjectID}}$				192.40 $_{\text{subjectID}}$			
	4.84 $_{\text{stim}}$				4.14 $_{\text{stim}}$			
ICC	0.52				0.30			
N	12 $_{\text{stim}}$				12 $_{\text{stim}}$			
	112 $_{\text{subjectID}}$				112 $_{\text{subjectID}}$			
Observations	1344				1344			
Marginal R^2 / Conditional R^2	0.108 / 0.568				0.024 / 0.317			

Note. p_{fdr}= p-values following False Discovery Rate multiple comparisons correction. Grandiosity = Grandiosity score from the Five-Factor Narcissism Inventory - Short Form. Valence = positive vs. negative cue word. Task = episodic memory vs. future simulation.

Table S1.3 *Study 1 Linear Mixed Effects Model Output for Subjective Rating Analyses with Vulnerability*

	Difficulty				Vividness				Visual Perspective				Simulation Frequency				Plausibility			
Predictors	β	95% CI	p	p_{fdr}	β	95% CI	p	p_{fdr}	β	95% CI	p	p_{fdr}	β	95% CI	p	p_{fdr}	β	95% CI	p	p_{fdr}
(Intercept)	3.71	2.40, 5.02	**<.001**	**<.001**	4.36	3.10-5.62	**<.001**	**<.001**	3.45	1.87-5.04	**<.001**	**<.001**	1.59	0.26, 2.92	**.020**	**.020**	5.25	4.13, 6.36	**<.001**	**<.001**
Vulnerability	-0.00	- 0.03, 0.02	.948	.948	-0.00	-0.03, 0.02	.741	.948	-0.00	-0.04, 0.03	.818	.948	0.02	-0.00, 0.05	.109	.552	-0.01	-0.03, 0.01	.312	.782
Valence (pos)	-1.40	-2.82, 0.03	.054	.136	0.12	-1.17, 1.42	.854	.854	0.75	-0.59, 2.08	.271	.339	1.12	-0.22, 2.46	.100	.167	1.38	0.03, 2.72	**.045**	.136
Task (memory)	-1.69	-3.08, -0.30	**.018**	.053	0.55	-0.71, 1.81	.392	.588	0.06	-1.28, 1.39	.935	.935								
Vulnerability x Valence	0.02	-0.01, 0.05	.151	.569	0.00	-0.02, 0.03	.907	.907	-0.02	-0.04, 0.01	.270	.569	-0.01	-0.03, 0.02	.579	.724	-0.01	-0.04, 0.01	.341	.569
Vulnerability x Task	0.02	-0.01, 0.05	.155	.464	0.00	-0.02, 0.03	.810	.810	-0.01	-0.04, 0.02	.527	.790								
Valence x Task	1.64	-0.33, 3.61	.103	.154	0.25	-1.54, 2.03	.786	.786	-2.13	-4.01, -0.24	**.027**	.082								
Vulnerability x Valence x Task	-0.03	-0.07, 0.01	.096	.143	-0.00	-0.04, 0.03	.933	.933	0.04	0.00, 0.08	**.029**	.087								
Random Effects																				
σ^2	2.66				2.18				2.47				2.18				2.33			
τ_{00}	$0.65_{\text{subjectID}}$				$0.69_{\text{subjectID}}$				$1.51_{\text{subjectID}}$				$0.31_{\text{subjectID}}$				$0.80_{\text{subjectID}}$			
ICC	0.07_{stim}				0.07_{stim}				0.00_{stim}				0.16_{stim}				0.07_{stim}			
	0.21				0.26								0.18				0.27			
N	12_{stim}				12_{stim}				12_{stim}				12_{stim}				12_{stim}			
	$112_{\text{subjectID}}$				$112_{\text{subjectID}}$				$112_{\text{subjectID}}$				$112_{\text{subjectID}}$				$112_{\text{subjectID}}$			
Observations	1344				1339				1342				670				671			
Marginal R^2 / Conditional R^2	0.050 / 0.252				0.057 / 0.302				0.013 / 0.388				0.062 / 0.228				0.051 / 0.309			

Note. p_{fdr} = p-values following False Discovery Rate multiple comparisons correction. Vulnerability = Vulnerability score from the Five-Factor Narcissism Inventory - Short Form. Valence = positive vs. negative cue word. Task = episodic memory vs. future simulation. Blank cell indicates that element is not applicable.

Table S1.4 *Study 1 Linear Mixed Effects Model Output for Objective Detail Analyses with Vulnerability*

	Internal Details				External Details			
Predictors	*β*	95% CI	*p*	p_{fdr}	*β*	95% CI	*p*	p_{fdr}
(Intercept)	72.06	40.39-103.73	**<.001**	**<.001**	31.38	11.97-50.79	**.002**	**.002**
Grandiosity	-0.47	-1.11-0.16	.140	.284	-0.01	-0.39-0.38	.968	.968
Valence (pos)	-13.73	-34.68-7.21	.199	.397	1.52	-16.84-19.88	.871	.871
Task (retrieval)	6.84	-13.99-27.66	.520	.520	-6.36	-24.61-11.88	.494	.520
Vulnerability x Valence	0.18	-0.24-0.59	.398	.796	0.00	-0.36-0.37	.979	.979
Vulnerability x Task	0.05	-0.36-0.47	.797	.967	-0.01	-0.37-0.36	.967	.967
Valence x Task	17.08	-12.38-46.53	.256	.511	-5.11	-30.91-20.70	.698	.698
Vulnerability x Valence x Task	-0.23	-0.82-0.36	.444	.825	0.06	-0.46-0.57	.825	.825
Random Effects								
σ^2	596.95				458.11			
τ_{00}	$724.45_{\text{subjectID}}$				$192.56_{\text{subjectID}}$			
	5.25_{stim}				4.23_{stim}			
ICC	0.55				0.30			
N	12_{stim}				12_{stim}			
	$112_{\text{subjectID}}$				$112_{\text{subjectID}}$			
Observations	1344				1344			
Marginal R^2 / Conditional R^2	0.040 / 0.568				0.024 / 0.317			

Note. p_{fdr} = *p*-values following False Discovery Rate multiple comparisons correction. Vulnerability = Vulnerability score from the Five-Factor Narcissism Inventory - Short Form. Valence = positive vs. negative cue word. Task = episodic memory vs. future simulation.

Table S1.5 *Study 1 Linear Mixed Effects Models Output for Communal vs. Agentic Exploratory Analyses*

	Difficulty				Vividness				Visual Perspective				Simulation Frequency				Plausibility			
Predictors	β	95% CI	*p*	p_{fdr}	β	95% CI	*p*	p_{fdr}	β	95% CI	*p*	p_{fdr}	β	95% CI	*p*	p_{fdr}	β	95% CI	*p*	p_{fdr}
(Intercept)	2.06	0.36, 3.76	**.018**	.022	0.53	4.00, 7.07	**<.001**	**<.001**	1.19	-0.49, 2.86	.164	**.164**	4.37	2.15, 6.58	**<.001**	**<.001**	5.50	3.53, 7.48	**<.001**	**<.001**
Grandiosity	0.01	-0.00, 0.03	.070	.175	-0.01	-0.02, 0.00	.193	.230	0.01	0.00, 0.03	**.039**	.175	-0.01	-0.03, 0.00	.130	.216	-0.01	-0.03, 0.01	.230	.230
Valence (pos)	2.21	-0.06, 4.49	.057	.071	-2.21	-4.20, -0.21	**.030**	.053	3.09	1.23, 4.96	**.001**	**.006**	-3.28	-6.26, -0.29	**.032**	.053	-1.43	-4.13, 1.28	.300	.300
Word Type (communal)	0.74	-1.53, 3.02	.521	.869	0.09	-1.92, 2.09	.933	.933	1.11	-0.75, 2.98	.242	.604	-2.29	-5.31, 0.74	.138	.604	-0.45	-3.23, 2.32	.748	.933
Grandiosity x Valence	-0.02	-0.04, -0.00	**.020**	**.034**	0.02	-0.00, 0.03	.054	.063	-0.03	-0.04, -0.01	**.001**	**.006**	0.03	0.01, 0.06	**.012**	**.031**	0.02	-0.00, 0.04	.063	.063
Grandiosity x Word Type	-0.01	-0.02, 0.01	.574	.578	-0.00	-0.02, 0.01	.578	.578	-0.01	-0.02, 0.01	.296	.494	0.02	-0.01, 0.04	.147	.315	0.00	-0.02, 0.03	.729	.367
Valence x Word Type	-1.77	-4.98, 1.45	.281	.469	0.75	-2.08, 3.58	.601	.601	-3.14	-5.78, -0.50	**.020**	.100	3.49	-1.05, 8.04	.131	.601	1.12	-2.81, 5.05	.574	.327
Grandiosity x Valence x Word Type	0.01	-0.01, 0.04	.388	.646	0.00	-0.02, 0.03	.824	.824	0.03	0.00, 0.05	**.020**	.101	-0.03	-0.07, 0.01	.103	.718	-0.01	-0.04, 0.02	.645	.258
Random Effects																				
σ^2	3.41				2.61				2.29				2.17				2.16			
τ_{00}	$0.41_{\text{subjectID}}$				$0.50_{\text{subjectID}}$				$1.40_{\text{subjectID}}$				$0.96_{\text{subjectID}}$				$0.25_{\text{subjectID}}$			
ICC	0.11				0.16				0.38				0.10				0.31			
N	$112_{\text{subjectID}}$				$112_{\text{subjectID}}$				$112_{\text{subjectID}}$				$112_{\text{subjectID}}$				$112_{\text{subjectID}}$			
Observations	448				446				448				224				224			
Marginal R^2 / Conditional R^2	0.041 / 0.143				0.043 / 0.197				0.019 / 0.392				0.148 / 0.235				0.042 / 0.336			

Note. p_{fdr} = *p*-values following False Discovery Rate multiple comparisons correction. Grandiosity = Grandiosity score from the Five-Factor Narcissism Inventory - Short Form. Valence = positive vs. negative cue word. Word Type = communal vs. agentic.

Table S1.6 *Replication Study Linear Mixed Effects Model Output for Objective Detail Analyses*

	Internal Details				External Details			
Predictors	β	95% CI	p	p_{fdr}	β	95% CI	p	p_{fdr}
(Intercept)	59.51	43.91 – 75.11	**<.001**	**<.001**	38.90	27.68 – 50.12	**<.001**	**<.001**
Grandiosity	-0.20	-0.33 – -0.07	**.003**	**.007**	-0.02	-0.11 – 0.07	.674	.674
Valence (pos)	-8.43	-20.54 – 3.67	.172	.345	3.91	-7.06 – 14.89	.485	.485
Task (retrieval)	19.97	8.94 – 31.01	**<.001**	**<.001**	-8.79	-19.00 – 1.42	.091	.092
Emotional Tone	0.21	-0.62 – 1.04	.616	.875	-0.06	-0.81 – 0.69	.875	.875
Grandiosity x Valence	0.00	-0.09 – 0.10	.945	.956	0.00	-0.09 – 0.09	.956	.956
Grandiosity x Task	-0.08	-0.17 – 0.01	.094	.188	0.01	-0.08 – 0.10	.833	.833
Valence x Task	-7.29	-22.87 – 8.29	.359	.392	6.29	-8.13 – 20.71	.392	.392
Grandiosity x Valence x Task	0.11	-0.03 – 0.24	.114	.229	-0.07	-0.20 – 0.05	.244	.244
Random Effects								
σ^2	538.21				461.07			
τ_{00}	516.53 $_{\text{subjectID}}$				204.36 $_{\text{subjectID}}$			
	8.50 $_{\text{stim}}$				3.75 $_{\text{stim}}$			
ICC	0.49				0.31			
N	12 $_{\text{stim}}$				12 $_{\text{stim}}$			
	169 $_{\text{subjectID}}$				169 $_{\text{subjectID}}$			
Observations	2028				2028			
Marginal R^2 / Conditional R^2	0.081 / 0.535				0.033 / 0.334			

Note. p_{fdr} = p-values following False Discovery Rate multiple comparisons correction. Grandiosity = Grandiosity score from the Five-Factor Narcissism Inventory - Short Form. Valence = positive vs. negative cue word. Task = episodic memory vs. future simulation.

Table S1.7 *Replication Study Linear Mixed Effects Model Output for Subjective Rating Analyses with Vulnerability*

	Difficulty				Vividness				Visual Perspective				Simulation Frequency				Plausibility			
Predictors	*β*	95% CI	*p*	p_{fdr}	*β*	95% CI	*p*	p_{fdr}	*β*	95% CI	*p*	p_{fdr}	*β*	95% CI	*p*	p_{fdr}	*β*	95% CI	*p*	p_{fdr}
(Intercept)	3.79	2.98, 4.60	**<.001**	**<.001**	4.51	3.81, 5.21	**<.001**	**<.001**	3.26	2.34, 4.18	**<.001**	**<.001**	2.09	1.35, 2.82	**<.001**	**<.001**	4.70	3.96, 5.44	**<.001**	**<.001**
Vulnerability	-0.00	-0.02, 0.01	.836	.886	0.00	-0.01, 0.02	.886	.886	0.01	-0.01- 0.03	.437	.729	0.02	0.00, 0.03	**.015**	.076	0.01	-0.01, 0.02	.228	.571
Valence (pos)	-0.69	-1.48, 0.10	.086	.144	0.24	-0.42, 0.90	.472	.472	-0.40	-1.17, 0.37	.310	.388	1.15	0.46, 1.85	**.001**	**.006**	0.86	0.04, 1.68	**.039**	.107
Task (memory)	-1.64	-2.40, -0.89	**<.001**	**<.001**	0.91	0.28, 1.55	**.005**	**.010**	-0.43	-1.19, 0.34	.273	.273	0.80	0.13, 1.47	**.019**	**.025**				
Vulnerability x Valence	0.01	-0.01, 0.02	.293	.489	-0.00	-0.01, 0.01	.789	.789	0.00	-0.01, 0.02	.555	.639	-0.01	-0.02, 0.00	.167	.417	0.01	-0.03, 0.00	.055	.274
Vulnerability x Task	0.01	-0.00, 0.03	.123	.246	-0.00	-0.02, 0.01	.540	.649	-0.00	-0.02, 0.01	.649	.649	-0.01	-0.02, 0.00	.116	.246				
Valence x Task	0.49	-0.58, 1.55	.369	.738	0.11	-0.78, 1.01	.803	.940	0.04	-1.04, 1.12	.940	.940	-0.82	-1.76, 0.12	.089	.356				
Vulnerability x Valence x Task	-0.00	-0.03, 0.02	.775	.803	-0.01	-0.02, 0.01	.565	.803	0.00	-0.02, 0.03	.803	.803	0.01	-0.01, 0.03	.510	.803				
Random Effects																				
σ^2	2.25				1.60				2.31				1.76				1.74			
τ_{00}	0.93 $_{subjectID}$				0.73 $_{subjectID}$				1.46 $_{subjectID}$				0.78 $_{subjectID}$				0.58 $_{subjectID}$			
ICC	0.05 $_{stim}$				0.02 $_{stim}$				0.01 $_{stim}$				0.03 $_{stim}$				0.18 $_{stim}$			
	0.30				0.32				0.39				0.32				0.30			
N	12 $_{stim}$				12 $_{stim}$				12 $_{stim}$				12 $_{stim}$				12 $_{stim}$			
	169 $_{subjectID}$				169 $_{subjectID}$				169 $_{subjectID}$				169 $_{subjectID}$				169 $_{subjectID}$			
Observations	2028				2028				2028				2028				2028			
Marginal R^2 / Conditional R^2	0.066 / 0.348				0.046 / 0.352				0.021 / 0.402				0.031 / 0.339				0.008 / 0.308			

Note. p_{fdr}= *p*-values following False Discovery Rate multiple comparisons correction. Vulnerability = Vulnerability score from the Five-Factor Narcissism Inventory - Short Form. Valence = positive vs. negative cue word. Task = episodic memory vs. future simulation. Blank cell indicates that element is not applicable.

Table S1.8 *Replication Study Linear Mixed Effects Model Output for Objective Detail Analyses with Vulnerability*

	Internal Details				External Details			
Predictors	*β*	95% CI	*p*	p_{fdr}	*β*	95% CI	*p*	p_{fdr}
(Intercept)	38.97	21.90-56.04	**<.001**	**<.001**	30.00	17.98-42.01	**<.001**	**<.001**
Vulnerability	-0.03	-0.38-0.32	.864	.864	0.14	-0.10-0.38	.262	.525
Valence (pos)	-5.22	-17.58-7.14	.408	.408	5.74	-5.49-16.96	.316	.408
Task (retrieval)	12.19	0.49-23.89	**.041**	.082	-3.67	-14.47-7.14	.506	.506
Emotional Tone	0.06	-0.75-0.88	.877	.983	-0.01	-0.75-0.73	.983	.983
Vulnerability x Valence	-0.05	-0.29-0.19	.677	.749	-0.04	-0.26-0.19	.749	.749
Vulnerability x Task	-0.03	-0.27-0.21	.812	.812	-0.09	-0.31-0.14	.449	.812
Valence x Task	-0.18	-16.71-16.34	.983	.983	1.98	-13.28-17.24	.799	.983
Vulnerability x Valence x Task	0.11	-0.23-0.45	.537	.598	-0.09	-0.40-0.23	.598	.598
Random Effects								
σ^2	539.82				460.88			
τ_{00}	$556.77_{\text{subjectID}}$				$204.97_{\text{subjectID}}$			
	8.49_{stim}				3.91_{stim}			
ICC	0.51				0.31			
N	12_{stim}				12_{stim}			
	$169_{\text{subjectID}}$				$169_{\text{subjectID}}$			
Observations	2028				2028			
Marginal R^2 / Conditional R^2	0.045 / 0.533				0.033 / 0.334			

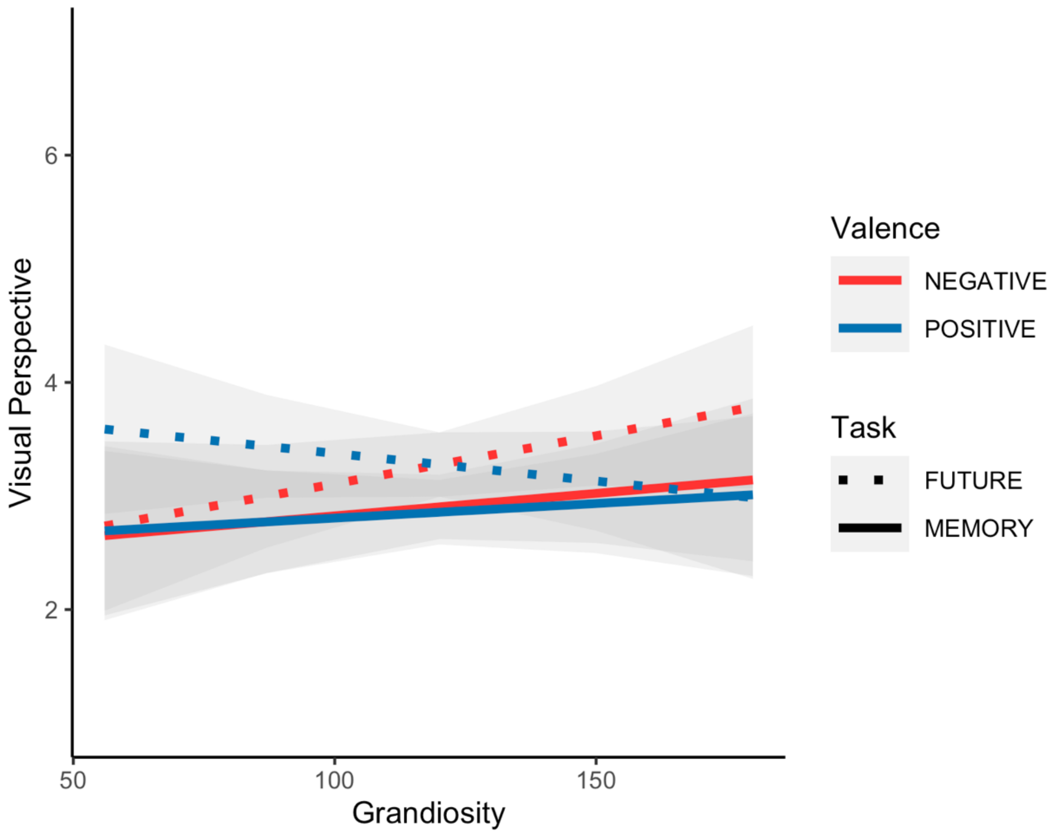
Note. p_{fdr} = *p*-values following False Discovery Rate multiple comparisons correction. Vulnerability = Vulnerability score from the Five-Factor Narcissism Inventory - Short Form. Valence = positive vs. negative cue word. Task = episodic memory vs. future simulation.

Table S1.9 *Replication Study Linear Mixed Effects Models Output for Communal vs. Agentic Exploratory Analyses*

	Difficulty				Vividness				Visual Perspective				Simulation Frequency				Plausibility			
Predictors	β	95% CI	p	p_{fdr}	β	95% CI	p	p_{fdr}	β	95% CI	p	p_{fdr}	β	95% CI	p	p_{fdr}	β	95% CI	p	p_{fdr}
(Intercept)	2.38	1.32, 3.44	**<.001**	**<.001**	5.33	4.39, 6.26	**<.001**	**<.001**	2.17	1.00, 3.34	**<.001**	**<.001**	2.71	1.81, 3.60	**<.001**	**<.001**	5.54	4.24, 6.84	**<.001**	**<.001**
Grandiosity	0.01	-0.00, 0.01	.234	.506	-0.00	-0.01, 0.01	.556	.556	0.01	-0.00, 0.02	.190	.506	0.00	-0.00, 0.01	.405	.506	-0.01	-0.02, 0.01	.344	.506
Valence (pos)	0.65	-0.81, 2.12	.382	.477	-1.01	-2.26, 0.25	.116	.193	0.37	-1.04, 1.78	.605	.605	-1.39	-2.56, -0.23	**.019**	.097	-1.59	-3.54, 0.36	.109	.193
Word Type (communal)	0.17	-1.17, 1.51	.805	.805	-0.26	-1.40, 0.89	.660	.805	0.88	-0.40, 2.16	.177	.684	-0.52	-1.59, 0.54	.336	.684	-0.77	-2.59, 1.06	.411	.684
Emotional Tone	0.02	-0.09, 0.12	.740	.804	0.01	-0.08, 0.10	.804	.804	0.13	0.03, 0.24	**.013**	**.045**	0.10	0.02, 0.19	**.018**	**.045**	0.14	0.01, 0.27	**.042**	.069
Grandiosity x Valence	-0.01	-0.02, 0.01	.350	.350	0.01	-0.00, 0.02	.118	.148	-0.01	-0.02, 0.00	.112	.148	0.01	0.00, 0.02	**.040**	.104	0.01	-0.01, 0.02	.289	.104
Grandiosity x Word Type	0.00	-0.01, 0.01	.928	.964	-0.00	-0.01, 0.01	.964	.964	-0.01	-0.02, 0.00	.170	.852	0.00	-0.01, 0.01	.819	.964	-0.00	-0.02, 0.01	.851	.964
Valence x Word Type	-0.99	-2.89, 0.90	.304	.759	0.36	-1.26, 1.97	.666	.833	-1.34	-3.15, 0.47	.147	.735	0.40	-1.11, 1.90	.606	.851	1.10	-1.55, 3.74	.416	.833
Grandiosity x Valence x Word Type	0.00	-0.01, 0.02	.637	.972	-0.00	-0.01, 0.01	.915	.972	0.01	-0.00, 0.03	.086	.429	-0.00	-0.01, 0.01	.972	.972	0.00	-0.02, 0.02	.896	.972
Random Effects																				
σ^2	2.65				1.94				2.42				1.68				2.08			
τ_{00}	0.66 subjectID				0.61 subjectID				1.57 subjectID				0.66 subjectID				0.34subjectID			
ICC	0.20				0.24				0.39				0.28				0.14			
N	169 subjectID				169 subjectID				169 subjectID				169 subjectID				169 subjectID			
Observations	676				676				676				676				338			
Marginal R^2 / Conditional R^2	0.015 / 0.212				0.010 / 0.247				0.015 / 0.402				0.058 / 0.324				0.088 / 0.216			

Note. p_{fdr}= *p*-values following False Discovery Rate multiple comparisons correction. Grandiosity = Grandiosity score from the Five-Factor Narcissism Inventory - Short Form. Valence = positive vs. negative cue word. Word Type = communal vs. agentic.

Figure S1.1 *Study 1 Subjective Rating Model: Visual Perspective*



Note. This figure depicts the fitted estimates of linear mixed effects models in which an interaction term between grandiosity and cue word valence (positive vs. negative) predicts visual perspective ratings (1 = entirely looking through my own eyes; 7 = entirely observing myself from an outside point of view). Random effects of participant ID and cue word are included. Grey area represents a 95% confidence interval. Grandiosity = Grandiosity subscale total score of the Five-Factor Narcissism Inventory-Short Form. This model was not replicated in the Replication Study.

Paper 2 Supplementary Materials

Table S2.1 *Regions displaying significantly different activity during univariate analysis of Memory and Future Thinking compared to the Sentence Control task.*

k	Peak Z	x,y,z {mm}	Region
54818	7.43	-15 -51 5	bilateral retrosplenial cortex/posterior cingulate cortex/medial prefrontal cortex/bilateral middle temporal gyrus/bilateral hippocampus/bilateral parahippocampal gyrus/right angular gyrus
	7.22	4 -56 18	
	7.14	4 33 5	
3716	6.41	-49 -61 25	left angular gyrus
	6.15	-44 -66 34	
	5.84	-61 -63 27	
936	6.4	-47 16 44	left precentral gyrus
	5.37	-40 10 49	
	4.56	-40 7 59	
779	5.63	9 -49 -46	bilateral cerebellum
	5.28	-10 -54 -46	
	4.79	7 -56 -38	
442	4.51	-1 -22 41	posterior cingulate cortex
	4.33	6 -24 34	
318	5.01	58 27 20	right lateral inferior frontal cortex
	3.73	41 21 25	
	3.54	43 24 17	
315	3.86	46 10 54	right precentral gyrus
	3.67	45 16 47	
	3.6	33 19 34	
303	4.23	52 -29 17	right posterior Sylvian fissure/parietal operculum
	3.81	57 -18 22	
	3.39	50 -29 30	
213	4.07	-44 -81 3	left inferior occipital gyrus
	4.06	-45 -90 1	
	3.53	-49 -85 10	

Note. Coordinates for cluster sub-peaks which lay in distinct cortical regions are listed directly below relevant peak cluster. Coordinates reflect centers of mass in MNI space. k = cluster size.

Table S2.2 *Regions displaying significantly different activity during univariate analysis of Memory and Future Thinking*

k	**Peak Z**	**x,y,z {mm}**	**Region**
Episodic retrieval > Episodic future thinking			
5265	5.05	11 -18 42	mid-cingulate cortex
	5.04	7 -66 63	
	4.89	-6 -54 68	
3374	5.55	55 -27 47	right supramarginal gyrus
	4.93	46 -81 22	
	4.57	58 -39 12	
2044	5.08	-32 46 35	left middle frontal gyrus
	5.04	-25 48 22	
	4.94	-34 45 27	
1370	4.47	-5 19 35	anterior cingulate cortex/mid-cingulate cortex
	4.41	11 33 27	
	4.23	-1 9 42	
1182	4.62	35 46 32	right middle frontal gyrus
	4.49	40 39 39	
	4.2	28 55 17	
999	4.73	-61 -37 39	left supramarginal gyrus
	4.14	-62 -32 46	
	4.04	-57 -47 32	
840	4.63	21 2 59	right superior frontal gyrus
	4.61	14 9 66	
	4.09	31 -1 64	
837	4.8	-47 -81 18	left middle occipital gyrus/posterior middle temporal gyrus
	4.02	-59 -59 -4	
	3.98	-49 -70 17	
672	4.4	-30 -8 61	left precentral gyrus
	4.24	-25 -8 51	
	4.12	-20 4 66	
394	4.43	-15 24 -0	left caudate/accumbens
	4.01	-17 14 -12	
	3.9	-10 7 -9	
386	4.77	6 9 -5	right caudate/accumbens
	4.24	24 12 12	
	4	14 24 1	
372	5.78	-39 2 3	left anterior insula/frontal operculum
	4.62	-32 16 12	

	3.37	-34 12 3	
313	4.36	50 7 10	right precentral gyrus
	3.67	55 10 20	
	3.3	41 10 15	
266	4.51	-23 55 -7	left anterior orbital gyrus
	3.88	-23 53 -16	
	3.42	-18 31 -16	
246	3.96	35 16 3	right anterior insula
	3.69	46 12 -2	
	3.06	58 7 0	
227	4.08	-40 -44 47	left supramarginal gyrus
	3.84	-28 -61 25	
	3.35	-34 -58 37	
175	4.36	-59 -15 0	left transverse temporal gyrus
	3.93	-54 -18 7	
155	3.76	26 -63 18	right posterior ventral precuneus/anterior cuneus
	3.69	21 -61 27	
	3.63	28 -54 13	
127	4.07	45 -27 -2	right superior temporal sulcus/middle temporal gyrus
	3.33	53 -25 -9	
	3.29	53 -25 0	
107	3.75	-30 -64 -53	left cerebellum
	3.38	-35 -58 -55	
Episodic Future Thinking > Episodic Retrieval			
k	Peak Z	x,y,z {mm}	Region
4376	5.08	-15 41 52	bilateral posterior superior frontal gyrus
	5.03	9 39 54	
	5	18 38 49	
2104	5.07	-6 22 -19	left medial prefrontal cortex
	4.81	7 45 -17	
	4.78	2 19 -14	
1538	5.02	-40 -87 -12	left inferior occipital gyrus
	4.83	-25 -92 -5	
	4.65	-34 -93 -9	
1129	4.99	-6 -63 20	bilateral retrosplenial cortex/posterior cingulate cortex
	4.64	9 -54 20	
	3.86	-8 -49 10	
1014	5.43	-34 21 -22	left posterior lateral orbital gyrus
	5.33	-45 33 -14	

	4.47	-42 24 -14	
819	4.42	-45 -63 27	left angular gyrus
	4.02	-40 -68 34	
	3.81	-45 -75 35	
710	5.1	67 -8 -19	right middle temporal gyrus
	4.39	53 -15 -26	
	4.37	60 -10 -24	
705	5.14	50 -63 30	right angular gyrus
	3.68	50 -71 35	
	2.98	41 -73 39	
681	4.81	-66 -10 -21	left middle temporal gyrus
	4.41	-69 -13 -14	
	4.2	-69 -22 -16	
635	4.36	38 -87 -14	right inferior occipital gyrus
	3.99	21 -98 -10	
	3.57	26 -90 -12	
624	4.89	46 41 -12	right lateral orbital gyrus/inferior frontal gyrus
	4.34	48 27 -10	
	2.6	38 26 -7	
372	4.52	-1 -54 -36	bilateral cerebellum
	4.3	4 -51 -48	
	4.09	-10 -53 -38	
157	5.07	26 19 -22	right posterior orbital gyrus
	3.62	36 24 -22	
	2.59	36 26 -31	
127	3.65	45 19 29	right middle frontal gyrus/inferior frontal sulcus
	2.87	55 17 35	
	2.87	31 16 29	

Note: Coordinates for cluster sub-peaks which lay in distinct cortical regions are listed directly below relevant peak cluster. Coordinates reflect centers of mass in MNI space. k = cluster size.

Table S2.3 *Regions demonstrating greater activity during trials with high location ratings than low location ratings*

k	**Peak Z**	**x,y,z {mm}**	**Region**
Memory High Location > Memory Low Location			
271	4.58	-10 -66 63	left superior parietal lobule/bilateral precuneus
	3.76	-1 -51 44	
	3.49	6 -49 49	
236	4.39	14 58 12	right superior frontal gyrus
	3.35	14 63 20	
	3.15	11 53 18	
155	3.57	9 -61 64	right superior parietal lobule
	3.23	12 -70 63	
123	4.22	-15 41 7	left anterior cingulate cortex
	4.14	-10 39 13	
	3.56	-8 41 1	
115	3.55	12 34 59	right posterior superior frontal gyrus
	3.13	21 34 54	
Future High Location > Future Low Location			
None			

Note: Coordinates for cluster sub-peaks which lay in distinct cortical regions are listed directly below relevant peak cluster. Coordinates reflect centers of mass in MNI space. k = cluster size.

Table S2.4 *Regions demonstrating greater activity during trials with high arrangement of people ratings than low arrangement of people ratings*

k	**Peak Z**	**x,y,z {mm}**	**Region**
Memory High Arrangement of People > Memory Low Arrangement of People			
3313	5.22	-23 -64 46	bilateral superior parietal lobule/precuneus/supramarginal gyrus
	5.1	-49 -44 54	
	4.95	41 -46 37	
459	4.4	62 -37 -22	right posterior inferior temporal gyrus
	4.34	58 -59 -10	
	4.24	52 -54 -14	
355	3.87	23 0 66	right posterior superior frontal gyrus/precentral gyrus/middle frontal gyrus
	3.85	26 -3 52	
	3.51	43 5 51	
279	4.29	28 43 27	right middle frontal gyrus/superior frontal gyrus
	3.99	16 43 37	
	3.94	28 36 35	
272	4.66	26 -64 -58	right cerebellum
	4.36	35 -63 -60	
	4.29	18 -83 -41	
200	3.55	4 -70 5	bilateral lingual gyrus/left calcarine cortex
	3.37	-1 -83 3	
	3.2	1 -80 -7	
190	4.06	-10 -102 -2	left occipital pole
	3.98	-3 -104 5	
	3.23	-3 -100 15	
149	4.32	40 26 30	right middle frontal gyrus
	3.82	31 17 25	
	3.62	26 21 32	
132	3.78	-25 -81 -19	left occipital fusiform gyrus/lingual gyrus
	2.91	-15 -83 -16	
131	4.72	2 -32 25	bilateral posterior cingulate cortex
	3.9	-5 -25 27	
125	3.89	-18 10 56	left posterior superior frontal gyrus
	3.85	-25 7 64	
	3.73	-23 -1 68	
112	3.86	31 -78 -19	right occipital fusiform gyrus
	3.72	24 -73 -16	
109	3.65	-22 5 27	left caudate
	3.41	-20 17 15	
	3.14	-22 12 22	
105	3.65	-51 -56 -4	left middle temporal gyrus
	3.23	-59 -66 -5	
	3.01	-57 -56 5	

Future High Arrangement of People > Future Low Arrangement of People
None

Note: Coordinates for cluster sub-peaks which lay in distinct cortical regions are listed directly below relevant peak cluster. Coordinates reflect centers of mass in MNI space. k = cluster size.

Table S2.5 *Output of Linear Mixed Effects Models Predicting Parameter Estimates for High and Low Location ratings in ROIs Defined by the Remember High Location > Remember Low Location median split analysis*

	mPFC ***14 58 12***				**L sup. parietal/PCU** ***-10 -66 63***				**aCC** ***-15 41 7***				**R sup. parietal/PCU** ***9 -61 64***				**dmPFC** ***12 34 59***			
Predictors	β	*95% CI*	*p*	p_{fdr}	β	*95% CI*	*p*	p_{fdr}	β	*95% CI*	*p*	p_{fdr}	β	*95% CI*	*p*	p_{fdr}	β	*95% CI*	*p*	p_{fdr}
(Intercept)	0.14	-0.40, 0.69	.608	.759	-3.07	-4.17, -1.96	**<.001**	**<.001**	0.03	-0.53, 0.59	.923	.956	-2.96	-4.08, -1.83	**<.001**	**<.001**	1.30	-0.10, 2.71	.069	.131
Task (memory)	0.66	-0.10, 1.42	.090	.154	2.61	1.31, 3.91	**<.001**	**.001**	0.75	0.05, 1.44	**.035**	.077	2.35	0.96, 3.74	**.001**	**.006**	-0.77	-2.55, 1.02	.396	.563
Rating (low)	-0.31	-1.07, 0.45	.413	.885	-0.33	-1.62, 0.97	.617	.885	0.16	-0.54, 0.85	.657	.885	-1.00	-2.38, 0.39	.157	.885	0.44	-1.35, 2.23	.625	.885
Task × Rating	-1.17	-2.24, -0.09	**.034**	.098	-1.82	-3.66, 0.01	.051	.127	-1.25	-2.24, -0.27	**.013**	**.047**	-1.62	-3.58, 0.34	.105	.212	-2.70	-5.23, -0.17	**.037**	.098
	Random Effects																			
σ^2	1.53				4.46				1.28				5.08				8.47			
τ_{00}	0.05 $_{id}$				2.04 $_{id}$				0.38 $_{id}$				1.57 $_{id}$				2.01 $_{id}$			
ICC	0.03				0.31				0.23				0.24				0.19			
N	21 $_{id}$				21 $_{id}$				21 $_{id}$				21 $_{id}$				21 $_{id}$			
Observations	84				84				84				84				84			
Marginal R^2 / Conditional R^2	0.156 / 0.181				0.170 / 0.431				0.088 / 0.295				0.193 / 0.383				0.147 / 0.311			

Note. p_{fdr} = *p*-values following False Discovery Rate multiple comparisons correction. Task = episodic memory vs. future thinking. Rating = high vs. low. mPFC = medial prefrontal cortex; PCU = precuneus; aCC = anterior cingulate cortex; dmPFC = dorsomedial prefrontal cortex. Coordinates at the center of each ROI are listed in MNI space.

Table S2.6 *Output of Linear Mixed Effects Models Predicting Parameter Estimates for High and Low Arrangement of People ratings in ROIs Defined by the Remember High Location > Remember Low Location median split analysis*

	mPFC *14 58 12*				**L sup. parietal/PCU** *-10 -66 63*				**aCC** *-15 41 7*				**R sup. parietal/PCU** *9 -61 64*				**dmPFC** *12 34 59*			
Predictors	β	*95% CI*	*p*	p_{fdr}	β	*95% CI*	*p*	p_{fdr}	β	*95% CI*	*p*	p_{fdr}	β	*95% CI*	*p*	p_{fdr}	β	*95% CI*	*p*	p_{fdr}
(Intercept)	0.08	-0.47, 0.63	.773	.848	-3.66	-5.06, -2.26	**<.001**	**<.001**	0.39	-0.10, 0.89	.115	.207	-3.91	-5.16, -2.65	**<.001**	**<.001**	0.46	-0.81, 1.72	.476	.647
Task (memory)	-0.09	-0.85, 0.68	.825	.877	3.19	1.34, 5.04	**.001**	**.006**	-0.02	-0.67, 0.63	.952	.980	3.58	2.09, 5.07	**<.001**	**<.001**	-1.44	-3.07, 0.20	.084	.153
Rating (low)	0.18	-0.59, 0.94	.649	.885	0.53	-1.32, 2.38	.569	.885	0.18	-0.47, 0.83	.586	.885	0.32	-1.17, 1.81	.672	.885	0.72	-0.92, 2.36	.384	.885
Task × Rating	-0.12	-1.21, 0.96	.820	.845	-3.42	-6.03, -0.80	**.011**	**.044**	-0.46	-1.38, 0.46	.319	.495	-2.25	-4.36, -0.15	**.036**	.098	-0.64	-2.95, 1.68	.586	.690
	Random Effects																			
σ^2	1.56				9.04				1.12				5.88				7.10			
τ_{00}	0.03_{id}				1.36_{id}				0.17_{id}				2.48_{id}				1.39_{id}			
ICC	0.02				0.13				0.13				0.30				0.16			
N	21_{id}				21_{id}				21_{id}				21_{id}				21_{id}			
Observations	84				84				84				84				84			
Marginal R^2 / Conditional R^2	0.006 / 0.025				0.137 / 0.249				0.023 / 0.148				0.194 / 0.433				0.091 / 0.240			

Note. p_{fdr} = *p*-values following False Discovery Rate multiple comparisons correction. Task = episodic memory vs. future thinking. Rating = high vs. low. mPFC = medial prefrontal cortex; PCU = precuneus; aCC = anterior cingulate cortex; dmPFC = dorsomedial prefrontal cortex. Coordinates at the center of each ROI are listed in MNI space.

Table S2.7 *Output of Linear Mixed Effects Models Predicting Parameter Estimates for High and Low Location ratings in ROIs Defined by the Remember High People > Remember Low People median split analysis*

	occipital pole ***-10 -102 -2***				**L dorsal premotor** ***-18 10 56***				**L SPL** ***-23 -64 46***				**L inferior occipital** ***-25 -81 -19***				**occipitotemporal** ***-51 -56 -4***			
Predictors	*β*	*95% CI*	*p*	p_{fdr}	*β*	*95% CI*	*p*	p_{fdr}	*β*	*95% CI*	*p*	p_{fdr}	*β*	*95% CI*	*p*	p_{fdr}	*β*	*95% CI*	*p*	p_{fdr}
(Intercept)	4.30	1.86, 6.74	**.001**	**.003**	-0.01	-0.46, 0.43	.948	.956	-0.03	-1.19, 1.13	.956	.956	3.90	1.62, 6.19	**.001**	**.005**	-0.37	-1.01, 0.27	.251	.356
Task (memory)	0.74	-2.05, 3.53	.600	.728	0.23	-0.32, 0.77	.416	.567	0.64	-0.47, 1.76	.253	.393	0.58	-1.54, 2.70	.589	.728	0.41	-0.39, 1.21	.310	.459
Rating (low)	0.28	-2.51, 3.07	.842	.921	0.04	-0.50, 0.59	.874	.921	0.46	-0.66, 1.57	.418	.885	0.31	-1.81, 2.43	.771	.921	-0.17	-0.97, 0.63	.681	.885
Task × Rating	-0.69	-4.64, 3.26	.729	.774	-0.59	-1.37, 0.18	.131	.249	-0.79	-2.37, 0.79	.323	.495	-1.38	-4.38, 1.61	.360	.511	-0.21	-1.35, 0.92	.707	.774
	Random Effects																			
σ^2	20.67				0.80				3.30				11.88				1.70			
τ_{00}	10.93_{id}				0.24_{id}				3.80_{id}				15.80_{id}				0.48_{id}			
ICC	0.35				0.23				0.54				0.57				0.22			
N	21_{id}				21_{id}				21_{id}				21_{id}				21_{id}			
Observations	84				84				84				84				84			
Marginal R^2 / Conditional R^2	0.002 / 0.347				0.037 / 0.262				0.008 / 0.539				0.006 / 0.573				0.020 / 0.236			

Note. p_{fdr} = *p*-values following False Discovery Rate multiple comparisons correction. Task = episodic memory vs. future thinking. Rating = high vs. low. SPL = superior parietal lobule. Coordinates at the center of each ROI are listed in MNI space.

Table S2.7 continued

	pCC ***2 -32 25***				**lingual** ***4 -70 5***				**R dorsal premotor** ***23 0 66***				**dlPFC 1** ***40 26 30***				**fusiform** ***31 -78 -19***			
Predictors	*β*	*95% CI*	*p*	p_{fdr}	*β*	*95% CI*	*p*	p_{fdr}	*β*	*95% CI*	*p*	p_{fdr}	*β*	*95% CI*	*p*	p_{fdr}	*β*	*95% CI*	*p*	p_{fdr}
(Intercept)	1.16	0.30, 2.02	**.009**	**.022**	0.70	-0.48, 1.88	.243	.356	-1.58	-2.34, -0.83	**<.001**	**<.001**	-1.45	-2.37, -0.52	**.003**	**.008**	2.16	0.49, 3.83	**.012**	**.030**
Task (memory)	0.24	-0.79, 1.27	.642	.728	0.01	-1.23, 1.25	.989	.989	1.13	0.22, 2.04	**.016**	**.040**	1.12	0.11, 2.14	**.030**	.071	0.19	-1.50, 1.88	.823	.877
Rating (low)	-0.24	-1.27, 0.78	.637	.885	-0.62	-1.86, 0.62	.324	.885	-0.20	-1.11, 0.72	.670	.885	-0.65	-1.66, 0.37	.207	.885	-0.03	-1.72, 1.66	.972	.972
Task × Rating	-0.26	-1.71, 1.19	.719	.774	0.48	-1.28, 2.23	.588	.690	-0.37	-1.66, 0.92	.566	.690	0.58	-0.86, 2.01	.425	.578	-0.77	-3.17, 1.62	.523	.685
	Random Effects																			
σ^2	2.78				4.08				2.21				2.73				7.60			
τ_{00}	1.13 $_{id}$				3.34 $_{id}$				0.82 $_{id}$				1.79 $_{id}$				7.21 $_{id}$			
ICC	0.29				0.45				0.27				0.40				0.49			
N	21 $_{id}$				21 $_{id}$				21 $_{id}$				21 $_{id}$				21 $_{id}$			
Observations	84				84				84				84				84			
Marginal R^2 / Conditional R^2	0.011 / 0.297				0.009 / 0.455				0.082 / 0.331				0.110 / 0.463				0.006 / 0.490			

Note. p_{fdr} = *p*-values following False Discovery Rate multiple comparisons correction. Task = episodic memory vs. future thinking. Rating = high vs. low. pCC = posterior cingulate cortex; dlPFC = dorsolateral prefrontal cortex. Coordinates at the center of each ROI are listed in MNI space.

Table S2.7 continued

	dlPFC 2 ***28 43 27***				**posterior inferior temporal gyrus** ***62 -37 -22***			
Predictors	*β*	*95% CI*	*p*	p_{fdr}	*β*	*95% CI*	*p*	p_{fdr}
(Intercept)	0.60	-0.16, 1.37	.121	.209	0.51	-0.29, 1.31	.209	.341
Task (memory)	0.19	-0.63, 1.02	.641	.728	0.35	-0.56, 1.26	.452	.592
Rating (low)	-0.38	-1.20, 0.44	.358	.885	-0.12	-1.03, 0.78	.785	.921
Task × Rating	-0.57	-1.73, 0.59	.334	.495	-0.00	-1.29, 1.29	1.000	1.000
	Random Effects							
σ^2	1.79				2.19			
τ_{00}	1.30_{id}				1.18_{id}			
ICC	0.42				0.35			
N	21_{id}				21_{id}			
Observations	84				84			
Marginal R^2 / Conditional R^2	0.042 / 0.446				0.010 / 0.357			

Note. p_{fdr} = *p*-values following False Discovery Rate multiple comparisons correction. Task = episodic memory vs. future thinking. Rating = high vs. low. dlPFC = dorsolateral prefrontal cortex. Coordinates at the center of each ROI are listed in MNI space.

Table S2.8 *Output of Linear Mixed Effects Models Predicting Parameter Estimates for High and Low People ratings in ROIs Defined by the Remember High People > Remember Low People median split analysis*

	occipital pole ***-10 -102 -2***				**L dorsal premotor** ***-18 10 56***				**L SPL** ***-23 -64 46***				**L inferior occipital** ***-25 -81 -19***				**occipitotemporal** ***-51 -56 -4***			
Predictors	β	*95% CI*	p	p_{fdr}	β	*95% CI*	p	p_{fdr}	β	*95% CI*	p	p_{fdr}	β	*95% CI*	p	p_{fdr}	β	*95% CI*	p	p_{fdr}
(Intercept)	4.63	2.69, 6.57	**<.001**	**<.001**	-0.25	-0.68, 0.18	.248	.356	-0.36	-1.51, 0.79	.536	.704	3.94	1.61, 6.27	**.001**	**.006**	-0.61	-1.23, 0.00	.050	.105
Task (memory)	1.57	-0.16, 3.30	.074	.142	0.70	0.19, 1.21	**.007**	**.024**	1.55	0.54, 2.57	**.003**	**.013**	1.36	-0.39, 3.12	.125	.205	1.19	0.57, 1.81	**<.001**	**.002**
Rating (low)	-0.12	-1.84, 1.61	.894	.921	-0.06	-0.57, 0.45	.814	.921	0.54	-0.48, 1.55	.298	.885	0.86	-0.89, 2.61	.332	.885	0.12	-0.50, 0.73	.702	.885
Task × Rating	-3.40	-5.84, -0.95	**.007**	**.032**	-0.70	-1.41, 0.02	.056	.129	-2.54	-3.98, -1.10	**.001**	**.015**	-4.06	-6.54, -1.58	**.002**	**.015**	-1.42	-2.30, -0.55	**.002**	**.015**
	Random Effects																			
σ^2	7.89				0.68				2.74				8.13				1.01			
τ_{00}	12.05_{id}				0.30_{id}				4.30_{id}				20.63_{id}				1.00_{id}			
ICC	0.60				0.31				0.61				0.72				0.50			
N	21_{id}				21_{id}				21_{id}				21_{id}				21_{id}			
Observations	84				84				84				84				84			
Marginal R^2 / Conditional R^2	0.073 / 0.633				0.096 / 0.375				0.074 / 0.640				0.050 / 0.731				0.121 / 0.560			

Note. p_{fdr} = *p*-values following False Discovery Rate multiple comparisons correction. Task = episodic memory vs. future thinking. Rating = high vs. low. SPL = superior parietal lobule. Coordinates at the center of each ROI are listed in MNI space.

Table S2.8 continued

	pCC				**lingual**				**R dorsal premotor**				**dlPFC 1**				**fusiform**			
	2 -32 25				***4 -70 5***				***23 0 66***				***40 26 30***				***31 -78 -19***			
Predictors	β	95% CI	p	p_{fdr}	β	95% CI	p	p_{fdr}	β	95% CI	p	p_{fdr}	β	95% CI	p	p_{fdr}	β	95% CI	p	p_{fdr}
(Intercept)	1.29	0.45, 2.13	**.003**	**.009**	-0.31	-1.54, 0.93	.623	.759	-2.05	-2.88, -1.22	**<.001**	**<.001**	-1.79	-2.73, -0.86	**<.001**	**.001**	1.77	0.20, 3.33	**.028**	.066
Task (memory)	0.88	-0.07, 1.84	.070	.142	1.77	0.70, 2.84	**.001**	**.007**	2.27	1.31, 3.22	**<.001**	**<.001**	2.69	1.56, 3.82	**<.001**	**<.001**	1.80	0.47, 3.13	**.008**	**.024**
Rating (low)	-0.38	-1.34, 0.58	.431	.885	0.66	-0.41, 1.73	.221	.885	0.36	-0.59, 1.32	.450	.885	-0.29	-1.42, 0.84	.612	.885	0.49	-0.84, 1.82	.465	.885
Task × Rating	-1.01	-2.36, 0.35	.143	.258	-2.42	-3.93, -0.91	**.002**	**.015**	-1.92	-3.27, -0.57	**.006**	**.030**	-1.03	-2.62, 0.57	.204	.348	-2.78	-4.66, -0.90	**.004**	**.026**
	Random Effects																			
σ^2	2.42				3.03				2.41				3.37				4.68			
τ_{00}	1.33 $_{id}$				5.07 $_{id}$				1.25 $_{id}$				1.23 $_{id}$				8.34 $_{id}$			
ICC	0.36				0.63				0.34				0.27				0.64			
N	21 $_{id}$				21 $_{id}$				21 $_{id}$				21 $_{id}$				21 $_{id}$			
Observations	84				84				84				84				84			
Marginal R^2 / Conditional R^2	0.073 / 0.402				0.061 / 0.649				0.171 / 0.454				0.237 / 0.441				0.054 / 0.660			

Note. p_{fdr} = *p*-values following False Discovery Rate multiple comparisons correction. Task = episodic memory vs. future thinking. Rating = high vs. low. pCC = posterior cingulate cortex; dlPFC = dorsolateral prefrontal cortex. Coordinates at the center of each ROI are listed in MNI space.

Table S2.8 continued

	dlPFC 2 ***28 43 27***				**posterior inferior temporal gyrus** ***62 -37 -22***			
Predictors	*β*	*95% CI*	*p*	*P_{fdr}*	*β*	*95% CI*	*p*	*p_{fdr}*
(Intercept)	0.15	-0.59, 0.88	.696	.818	0.13	-0.67, 0.92	.752	.848
Task (memory)	0.87	0.28, 1.45	**.004**	**.015**	1.35	0.36, 2.35	**.008**	**.024**
Rating (low)	0.45	-0.14, 1.03	.133	.885	0.51	-0.48, 1.51	.310	.885
Task × Rating	-1.51	-2.34, -0.68	**<.001**	**.015**	-1.29	-2.70, 0.12	.071	.154
	Random Effects							
σ^2	0.91				2.62			
τ_{00}	1.97 $_{\text{id}}$				0.73 $_{\text{id}}$			
ICC	0.68				0.22			
N	21 $_{\text{id}}$				21 $_{\text{id}}$			
Observations	84				84			
Marginal R^2 / Conditional R^2	0.056 / 0.703				0.066 / 0.269			

Note. p_{fdr} = *p*-values following False Discovery Rate multiple comparisons correction. Task = episodic memory vs. future thinking. Rating = high vs. low. dlPFC = dorsolateral prefrontal cortex. Coordinates at the center of each ROI are listed in MNI space.

Table S2.9 *Regions parametrically modulated by ratings during Memory trials*

k	**Peak Z**	**x,y,z {mm}**	**Region**
Memory Location Rating Parametric Modulation			
783	4.17	7 -68 54	right precuneus/superior parietal lobule/left precuneus
	4.06	14 -73 59	
	3.93	-6 -54 44	
499	4.3	35 -63 47	right angular gyrus/superior parietal lobule
	4.14	36 -47 54	
	3.92	43 -37 51	
342	4.28	-40 -41 37	left supramarginal gyrus/superior parietal lobule
	3.71	-42 -39 47	
	3.49	-45 -47 56	
285	3.88	24 2 52	right superior frontal gyrus/middle frontal gyrus
	3.81	16 7 51	
	3.77	29 4 63	
258	4.02	12 5 1	right caudate/putamen
	3.87	21 7 0	
	3.85	21 17 17	
233	5.05	16 -15 10	right thalamus
	3.5	12 -27 8	
	3.48	7 -17 12	
114	3.6	-11 51 3	bilateral medial prefrontal cortex/anterior superior frontal gyrus
	3.22	-1 58 5	
Memory People Rating Parametric Modulation			
1628	4.33	-18 -66 52	bilateral superior parietal lobule/precuneus
	4.25	16 -71 56	
	4.07	7 -75 56	
568	4.48	1 -80 -7	bilateral lingual gyrus/left calcarine cortex
	4.38	2 -71 8	
	4.13	-5 -87 3	
309	4.49	48 -35 52	right supramarginal gyrus/superior parietal lobule
	3.15	43 -32 42	
	3.11	40 -51 52	
307	4.09	-44 -54 -41	left cerebellum
	3.83	-39 -46 -39	
	3.56	-40 -53 -27	
257	4.16	35 36 39	right anterior middle frontal gyrus/superior frontal gyrus
	3.18	29 53 34	
	3.05	24 39 35	
248	4.38	31 2 66	right posterior middle frontal gyrus/superior frontal gyrus
	4.27	23 0 63	
	3.01	19 0 73	
238	5.11	-51 -44 54	left supramarginal gyrus
	4.12	-45 -42 41	

	3.42	-51 -49 44	
217	4.52	12 -18 10	bilateral thalamus
	4.13	7 -7 10	
	3.43	-8 -22 7	
202	4.08	11 29 32	right medial superior frontal gyrus/bilateral anterior cingulate cortex
	4.08	2 26 29	
	3.43	-11 26 25	
150	4.24	35 -64 -21	right cerebellum
	4.12	38 -64 -31	
136	4.06	-22 2 68	left posterior superior frontal gyrus
	3.79	-13 5 64	
	3.35	-17 9 58	
128	3.49	9 -100 10	right occipital pole
	3.39	12 -105 -4	
123	3.86	-32 -59 46	left angular gyrus/superior parietal lobule
	3.51	-27 -51 44	
	3.32	-34 -53 52	
108	3.98	-30 -68 1	left calcarine sulcus
	3.97	-25 -75 7	
	3.69	-17 -70 1	

Note: Coordinates for cluster sub-peaks which lay in distinct cortical regions are listed directly below relevant peak cluster. Coordinates reflect centers of mass in MNI space. k = cluster size.

Table S2.10 *Regions parametrically modulated by ratings during Future Thinking trials*

k	**Peak Z**	**x,y,z {mm}**	**Region**
Future Location Rating Parametric Modulation			
408	4.07	40 -54 61	right superior parietal lobule
	3.97	21 -70 64	
	3.63	33 -63 63	
309	3.65	-6 -64 66	left superior parietal lobule/precuneus
	3.63	-6 -56 71	
	3.53	-15 -70 61	
194	4.1	-39 -71 17	left middle occipital gyrus
	4.05	-42 -80 18	
	3.6	-35 -76 10	
138	3.45	-45 -58 -34	left cerebellum
	3.42	-49 -53 -44	
	2.92	-51 -61 -43	
174	3.67	50 22 27	right middle frontal gyrus
	3.19	40 19 25	
127	4.17	-28 -88 -29	left cerebellum
	4.03	-23 -90 -36	
	3.68	-20 -92 -27	
123	4.32	-23 -71 -39	left cerebellum
	3.59	-30 -76 -51	
	3.24	-20 -76 -46	
119	4.31	40 2 61	right posterior middle frontal gyrus
	3.83	45 9 54	
	2.93	36 5 52	
Future People Rating Parametric Modulation			
108	3.93	6 -63 59	right precuneus
	3.36	12 -54 46	
108	3.89	-1 -42 37	bilateral posterior cingulate cortex
	3.29	-10 -34 41	
	3.2	9 -42 34	

Note: Coordinates for cluster sub-peaks which lay in distinct cortical regions are listed directly below relevant peak cluster. Coordinates reflect centers of mass in MNI space. k = cluster size.

Paper 3 Supplementary Materials

Supplementary Materials and Methods

TMS-specific recruitment parameters

As in our prior repetitive transcranial magnetic stimulation (rTMS) study (Thakral et al., 2017), participants were excluded from participation if they might be pregnant, had a current or previous neuropsychiatric or neurological illness, were taking any psychoactive medications, had a prior head injury that required hospitalization, had a history of concussions, had experienced frequent or severe headaches, had a prior experience of a seizure, had a diagnosis or family history of epilepsy, or were diabetic. Before participating in each continuous theta-burst (cTBS) session, participants self-reported to not have consumed alcohol in the last 24h and not to have consumed caffeinated drinks in the last 2h.

Object stimuli and task presentation

Experimental materials comprised 162 object cue words denoting common, everyday objects drawn from prior related studies (e.g., Beaty et al., 2018; Madore et al., 2016, 2019). The cues were divided into 18 lists (i.e., 3 cTBS sessions (no-cTBS, vertex, or AG) by 3 tasks (episodic simulation, 18 divergent thinking, non-episodic control) by 2 runs). As in our prior rTMS study (Thakral et al., 2017), cue lists were counterbalanced as a function of cTBS site and task. All stimuli were shown on a black screen in white 25-point Arial font. Stimuli were present using the Cogent 21 software package (http://vislab.ucl.ac.uk/cogent.php) as implemented in MATLAB (The MathWorks, Natick, MA, USA).

Post-scan subjective ratings

For each simulation trial, participants rated the similarity of the event to a prior experience (5-point scale: ‘never anything similar’ to ‘this event exactly’), its plausibility (5-point scale: ‘not at all’ to ‘extremely’), and whether it was within the next 1-5 years (binary response: ‘yes’ or ‘no’). For each divergent thinking trial, participants rated the similarity of the uses generated to prior experiences (5-point scale: ‘not at all’ to ‘extremely’) and how creative (original and novel) they thought their uses were on average (5-point scale: ‘not at all’ to ‘extremely’). For each control trial, participants rated the familiarity of the objects generated on average (5-point scale: ‘not at all’ to ‘extremely’) and the typicality (semantically and thematically related) of them (5-point scale: ‘not at all’ to ‘extremely’). At the end of the session, participants also viewed each use generated for the AUT and rated each as either ‘old’ or ‘new’, with an old idea being a previous memory or thought before the study and a new idea being a thought that came to mind for the first time during the study (see also Benedek et al., 2014; Gilhooly et al., 2007; Madore et al., 2016, 2019). These data were collected for exploratory purposes outside the current study’s scope (note also that due to trial numbers, an analysis of old vs. new ideas would be statistically underpowered).

Post-scan interview scoring

Each future event was segmented into internal and external details. Internal or episodic details refer to those of the main event that are specific in both time and place (i.e., the who, what, when, and where details of the central event). External or non-episodic details include factual, off-topic, metacognitive, or repetitive information (for other examples of this scoring approach, see Gaesser et al., 2011; Madore et al., 2014; Madore & Schacter, 2016; Thakral et al., 2017, 2020). Internal details for the control task refer to those of the object definitions (including the two associated objects generated for each trial) that are on-task and meaningful. External details refer to details that are off-topic, repetitive, not meaningful, or commentary. Quantitative measures included fluency (i.e., total appropriate uses generated excluding repetitions), flexibility (i.e., the number of distinct categories that appropriate uses could be classified under), and elaboration (i.e., a rating of the level of detail associated ranging from 0 to 2; see Guilford, 1967). A single qualitative measure was computed as originality (i.e., a rating of the perceived novelty and appropriateness of each use, ranging from 1 to 4, with scores of 3 and 4 given to only a few uses per participant (Benedek et al., 2014). For each measure, the scores were averaged across trials to create a standardized measure of performance.

fMRI acquisition, preprocessing, and analysis parameters

For task-based scanning, functional images were acquired with a multiband echo-planar imaging sequence (University of Minnesota C2P sequence: repetition time (TR) of 2s, echo time (TE) of 30ms, matrix size of 124×124, 87 slices (3 slices acquired simultaneously), 1.7mm^3 resolution). The slices were auto-aligned to an angle 20° toward coronal from anterior–posterior commissure alignment. Anatomic images were acquired with a magnetization-prepared rapid gradient echo sequence (1mm^3 resolution).

Task-based functional image preprocessing in SPM12 included slice-time correction, two-pass spatial realignment, and normalization into Montreal Neurological Institute (MNI) space (images were not resampled). Functional images were smoothed with a 3mm full-width half-maximum (FWHM) Gaussian kernel. Anatomic images were normalized into MNI space using an analogous procedure to that employed for the functional images.

For resting-state scanning, images were acquired with a multiband echo-planar imaging sequence (TR of 650ms, TE 34.80ms, matrix size of 90x90, 64 slices (8 slices acquired simultaneously), 2.3mm^3 resolution). The slices were auto-aligned to an angle 20° toward coronal from anterior–posterior commissure alignment. Note the acquisition parameters differed from the functional data to maximize scanner capabilities. The first four TRs of each resting-state scan were removed to minimize T1-saturation. The data were realigned, spatially normalized to the MNI template, and resampled to 2 mm^3. 8 Resting-state specific preprocessing steps were conducted in FSL 4.1.7 (FMRIB) and SPM12 (Van Dijk et al., 2010). Data were smoothed with a 4mm Gaussian kernel and filtered to retain frequencies below 0.08Hz. Partial regression was used to create a series of regressors reflecting variance of non-neural sources (i.e., noise). These regressors included 6 motion parameters, the averaged signal within cerebrospinal fluid, an ROI within deep white matter, and an ROI comprising the whole brain (i.e., global signal regression; Murphy & Fox, 2017). We also included each regressor's first temporal derivative to correct for potential temporal shifts in BOLD signal.

We also conducted an analysis to test for the specificity of the effect of cTBS on connectivity between the hippocampal seed and AG target site (i.e., we compared the hippocampus-to-AG connectivity to connectivity to other 'control' locations). Specifically, we examined whether cTBS to the AG relative to the vertex also changed connectivity between the hippocampal seed and two other known resting-state fMRI networks. On an individual participant basis, we extracted the connectivity values for regions belonging to the frontoparietal control network (FPCN) and the visual attention network (VAN) using the functional-anatomic characterization reported by Vincent et al. (2008; see Table 2 in Vincent et al. for coordinates). The FPCN regions included the anterior cingulate, right and left dorsolateral prefrontal cortex, left and right anterior insula, and left and right anterior inferior parietal lobule (7 regions). The VAN regions included left and right frontal eye fields, and left and right superior parietal lobule (4 regions). Connectivity values were averaged across regions within a given network (mean hippocampus-to6 FPCN connectivity (± 1 standard error) following vertex cTBS and AG cTBS was -0.005±0.02 and -0.04±0.02, respectively, and mean hippocampus-to-VAN connectivity following vertex cTBS and AG cTBS was -0.066 ±0.02 and -0.08±0.01, respectively. We adopted an ROI approach relative to a whole-brain connectivity analysis to directly compare the originally reported seed-to-target connectivity analysis to the connectivity in regions of the FPCN and VAN.

We also performed a parametric modulation analysis in SPM by including regressors in the first-level models (for similar procedures, see Madore et al., 2016; Thakral et al., 2020). Although we employed fMRI-guided cTBS to specifically manipulate episodic relative to non-episodic processing, this additional analysis was carried out to further relate the behavioral and neural data. We entered, on a trial specific basis, a behavioral score for each imagined event, divergent thinking, and non-episodic control trial as a covariate of interest (i.e., regressor for each trial/detail type). The detail scored was modeled linearly, represented the orthogonal contribution of detail in the absence of any other covariates, and was mean-centered according to SPM algorithms. At the second level, parameter estimates for the six covariates of interest (i.e., behavioral scores for the construction-related activity for each of the three tasks and two cTBS sites) and for each participant were entered into a repeated-measures ANOVA. We then conducted the identical interaction contrast as the main analysis (i.e., the vertex > AG contrast for the episodic simulation + divergent thinking > non-episodic control). This parametric modulation analysis identifies those voxels that during construction demonstrate differential activity following the cTBS to the AG vs. vertex as modulated by an index of detail for imagined events and divergent thinking over the non-episodic control task.

cTBS protocol for TMS manipulation

The cTBS protocol was composed of 50Hz triplets (three single pulses separated by 20msec) repeated at a frequency of 5Hz (every 200msec) for a duration of 40sec (or 9 600 pulses) using parameters from Huang et al. (2005; for other studies employing this protocol, see

Bonnici et al., 2018; Tambini et al., 2018; Yazar et al., 2014). This TMS protocol was assumed to be inhibitory and impair performance. This assumption is based on prior studies demonstrating that cTBS reduces cortical excitability (Huang et al., 2005), univariate fMRI activity (Hubl et al., 2008), and has been shown to disrupt behavioral performance during episodic memory (Yazar et al., 2014) and in autobiographical memory tasks (Bonnici et al., 2018; Hebscher et al., 2019) akin to those employed in the current study. cTBS intensity was determined from the participant-specific motor threshold. In this procedure (e.g., Koen et al., 2018), the left motor cortex was identified on each participant's anatomic image and motor threshold was defined as the lowest single-pulse TMS intensity that produced 5 out of 10 motor responses in the right hand (i.e., visual detection of a finger twitch in the right hand; motor threshold was set at 70% of stimulator output if no twitch was evident at this intensity). Once identified, cTBS intensity was set at 90% of the resting motor threshold. Mean cTBS intensity was 54.66±2.13% (i.e., resting motor threshold of 60.73). Relative to our previous TMS study which employed rTMS (i.e., 1Hz for 10min), here we employed cTBS for the specific purpose of being able to acquire fMRI data. In contrast to rTMS, cTBS disrupts neural activity with shorter TMS durations (i.e., 40s relative to 60min of 1Hz TMS which would produce roughly equivalent durations of inhibitory TMS effects). Therefore, for reasons of participant comfort and overall feasibility, we adopted a cTBS as opposed to rTMS protocol.

Brainsight neuronavigation to implement TMS

To apply the cTBS and implement real-time tracking of the TMS coil and anatomic image on a participant-to-participant basis with Brainsight neuronavigation, three landmarks were identified on the participant-specific anatomic image (nasion, left preauricular, and right preauricular) and then coregistered. Reflective markers were also attached to the TMS coil which emitted signals picked up by an infrared camera. The coil was positioned perpendicular to the cTBS site and maintained at an angle 45° away from the midline (see also Slotnick & Thakral, 2011; Thakral et al., 2011, 2020). The TMS coil was initially placed at the target location. The coil was held in place by experimenter, with the TMS coil kept within 1-2mm from the target location during the TMS application.

Supplementary Results

Subjective Ratings

Behavioral variables collected in the scanner for the three tasks did not vary as a function of cTBS site (i.e., task difficulty or vividness rating; Fs(2,34)<1.40, ps>0.26; see Table S3.1). Consistent with prior findings, participants experienced the divergent thinking task as greatest in difficulty and the episodic simulation task as greatest in vividness relative to the other two tasks, respectively (Madore et al., 2016, 2019). Analyses of the post-scan ratings also revealed null effects of cTBS site (ts(17)<1.47, ps>0.16; see Table S3.2). In general, future episodes were rated as plausible and not very similar to past experiences, and non-episodic control trials involved very familiar and typical objects. For the divergent thinking task, post-scan ratings indicated that generated uses were dissimilar to previous experiences, and creative. Taken together, these in-scan and post-scan ratings verify overall task compliance and confirm that participants performed the tasks adequately.

Divergent thinking metrics

Uses generated were scored as ‘somewhat detailed’ and ‘somewhat creative’, with these average elaboration and originality ratings not significantly differing as a function of cTBS site (0.99±0.08 and 1.75±0.06, respectively; ts(17)<2.00, ps>0.06).

Table S3.1

	Episodic simulation		**Divergent Thinking**		**Non-episodic control**	
Rating	**Vertex**	**AG**	**Vertex**	**AG**	**Vertex**	**AG**
Difficulty	1.15 (0.12)	1.08 (0.11)	2.03 (0.14)	1.82 (0.15)	1.35 (0.12)	1.35 (0.14)
Vividness	2.39 (0.11)	2.5 (0.10)	1.91 (0.13)	1.89 (0.12)	2.03 (0.12)	2.02 (0.13)

Note. Mean difficulty and vividness (± 1 standard error of the mean) for each 3 task (episodic simulation, divergent thinking, and non-episodic control) 4 and stimulation site (vertex and AG). Both ratings were made on a 5-point 5 scale with lower ratings reflecting reduced vividness and difficulty. As reported in the main text, for either the in-scan vividness or difficulty rating there was no interaction as a function of cTBS site. For either rating there were also no main effects of cTBS site (Fs, 1, 17) < 2.09, ps > 0.17), but the main effects of Task were significant (Fs(2, 34) > 15.60, ps < 0.001, partial η2s > 0.48). Follow-up t-tests revealed that the episodic simulation task was experienced as greater in vividness than both the divergent thinking and control tasks (ts(17) > 3.77, ps < 0.002, ds > 0.89), with no other comparisons significant (t(17) = 1.28, p = 0.22). In addition, the divergent thinking task was experienced as greater in difficulty than both the episodic simulation and non-episodic control task (ts(17) > 5.31, ps < 0.001, ds > 1.25), with no other comparison significant (t(17) = 2.00, p = 0.06).

Table S3.2

<table>
<tr><th colspan="3">Episodic simulation</th></tr>
<tr><th>Rating</th><th>Vertex</th><th>AG</th></tr>
<tr><td>Similarity to a past event</td><td>2.51 (0.19)</td><td>2.52 (0.18)</td></tr>
<tr><td>Plausibility of the event</td><td>2.71 (0.18)</td><td>2.92 (0.16)</td></tr>
<tr><th colspan="3">Divergent thinking</th></tr>
<tr><th>Rating</th><th>Vertex</th><th>AG</th></tr>
<tr><td>Self-rated creativity</td><td>3.05 (0.14)</td><td>3.01 (0.13)</td></tr>
<tr><td>Similarity of uses to prior experience</td><td>2.33 (0.15)</td><td>2.32 (0.16)</td></tr>
<tr><th colspan="3">Non-episodic control</th></tr>
<tr><th>Rating</th><th>Vertex</th><th>AG</th></tr>
<tr><td>Familiarity of objects generated</td><td>4.15 (0.10)</td><td>4.17 (0.10)</td></tr>
<tr><td>Typicality of objects generated</td><td>4.18 (0.11)</td><td>4.15 (0.10)</td></tr>
</table>

Note. Mean post-scan ratings made on a 5-point scale ranging from least to most (± 1 standard error of the mean) for each task (episodic simulation, divergent thinking, and non-episodic control) and stimulation site (vertex and AG). As reported in the main text, no significant differences emerged when comparing each post-scan rating as a function of cTBS site.

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