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Remembering what could have happened: Neural correlates of episodic counterfactual thinking

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ABSTRACT

Recent evidence suggests that our capacities to remember the past and to imagine what might happen in the future largely depend on the same core brain network that includes the middle temporal lobe, the posterior cingulate/retrosplenial cortex, the inferior parietal lobe, the medial prefrontal cortex, and the lateral temporal cortex. However, the extent to which regions of this core brain network are also responsible for our capacity to think about what *could* have happened in our past, yet did not occur (i.e., episodic counterfactual thinking), is still unknown. The present study examined this issue. Using a variation of the experimental recombination paradigm (Addis, Pan, Vu, Laiser, & Schacter, 2009. *Neuropsychologia*. 47: 2222–2238), participants were asked both to remember personal past events and to envision alternative outcomes to such events while undergoing functional magnetic resonance imaging. Three sets of analyses were performed on the imaging data in order to investigate two related issues. First, a mean-centered spatiotemporal partial least square (PLS) analysis identified a pattern of brain activity across regions of the core network that was common to episodic memory and episodic counterfactual thinking. Second, a non-rotated PLS analysis identified two different patterns of brain activity for likely and unlikely episodic counterfactual thoughts, with the former showing significant overlap with the set of regions engaged during episodic recollection. Finally, a parametric modulation was conducted to explore the differential engagement of brain regions during counterfactual thinking, revealing that areas such as the parahippocampal gyrus and the right hippocampus were modulated by the subjective likelihood of counterfactual simulations. These results suggest that episodic counterfactual thinking engages regions that form the core brain network, and also that the subjective likelihood of our counterfactual thoughts modulates the engagement of different areas within this set of regions.

1. Introduction

Traditionally, the notion of episodic memory has been used in reference to the psychological capacity to remember the past (Tulving, 1985). As a result, most research on episodic memory has focused on episodic recollection: the cognitive process of bringing past experiences back to mind (Tulving, 2002). However, recent evidence suggests striking commonalities between the cognitive and neural processes required to remember one's past and those required to imagine one's future (for recent reviews, see Schacter, Addis, & Buckner, 2008; Schacter, Addis, Hassabis, Martin, Spreng, & Szpunar, 2012; Szpunar, 2010). Evidence from three lines of research supports this claim. First, neuropsychological studies with populations known to have episodic memory deficits, such as patients with amnesia (Tulving, 1985; Klein, Loftus, & Kihlstrom, 2002; Hassabis, Kumaran, Vann, & Maguire, 2007; Race, Keane, & Verfaellie, 2011; but see Squire et al., 2010), severe depression (Dickson & Bates, 2005; Williams et al., 1996), schizophrenia (D'Argembeau, Raffard, & Van der Linden, 2008), Alzheimer's disease (Addis, Sacchetti, Ally, Budson, & Schacter, 2009) and mild cognitive impairment (Gamboz et al., 2010) show that they also exhibit impairments when mentally simulating events that may happen in their future, a cognitive process that has come to be known as *episodic future thinking* (Atance & O'Neill, 2001; Szpunar, 2010). Similar parallels between remembering the past and imagining the future have been observed in young children (Atance & O'Neill, 2001; Suddendorf & Busby,

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2005) as well as in healthy old adults (Addis, Wong, & Schacter, 2008; Addis, Musicaro, Pan, & Schacter, 2010; Gaesser, Sacchetti, Addis, & Schacter, 2011; Spreng & Levine, 2006). Second, behavioral studies examining the phenomenological characteristics of episodic memory and episodic future thinking indicate that both processes are supported by common cognitive mechanisms (D'Argembeau & Van der Linden, 2004, 2006; D'Argembeau et al., 2009; Szpunar & McDermott, 2008). Third, functional neuroimaging studies comparing episodic memory and future thinking have revealed a common "core" brain network that is engaged during both processes (Addis, Wong, & Schacter, 2007; Addis & Schacter, 2008; Hassabis, Kumaran, &Maguire, 2007; Szpunar, Watson, & McDermott, 2007; Okuda et al., 2003). This core network, which overlaps substantially with the default network (Buckner, Andrews-Hanna, & Schacter, 2008), involves primarily the medial temporal lobes (including the hippocampus), the cingulate/retrosplenial cortex, the inferior parietal lobe, the medial prefrontal cortex, and the lateral temporal cortex (Buckner & Carroll, 2007; Schacter, Addis, & Buckner, 2007).

To account for the phenomenological, neural and cognitive commonalities between remembering one's past and imagining one's future, Schacter and Addis (2007) put forth the constructive episodic simulation hypothesis. According to this hypothesis, episodic future thinking relies on much the same neural mechanisms, and shares much of the same phenomenological characteristics, as episodic memory because both cognitive operations depend on similar processes. When we remember an event, episodic memory processes reintegrate representational contents from the encoded experience to reconstruct the unified mental simulation we call recollection. Similarly, when we engage in episodic future thinking, some of the same processes recombine components from past experiences into a novel, yet memory-dependent, simulation of what may occur in the future. However, the finding of common activations during both processes is consistent with an alternative hypothesis: Thinking about the future need not involve the recombination of components, but rather, may entail the mere recasting of a previous experience as a future event. By this "recasting" account, thinking about the future would consist of a two-fold process: An initial recollection of a specific past experience, followed by imagining that experience occurring not in the past, but in the future. Thus, recasting could explain why brain regions related to episodic memory are engaged during episodic future thinking, without postulating the flexible recombination of episodic components, as suggested by the constructive episodic simulation hypothesis.

In a recent study, Addis, Pan, Vu, Laiser, and Schacter (2009) tested the constructive episodic simulation hypothesis as an alternative to the recasting view using an *experimental recombination procedure*. This paradigm consists of collecting episodic memories from participants in order to extract details from the reported episodes. Such event details or components are subsequently recombined during a scanning session in which they are employed as visual cues. Addis and colleagues presented participants with three components (i.e., person, object and place) extracted from participants' memories. In one condition, all components belonged to the same memory and participants were simply asked to remember the event to which such episodic details belonged. In a second condition, participants were presented with randomly recombined components of their memories and were asked to imagine a future event that would include such event details. Finally, in a third condition, participants were presented with randomly recombined components of their reported memories, but were asked to imagine an alternative *past* event including such disjoint event details. Using spatiotemporal partial least squares analysis (PLS), Addis et al. (2009) found that all three conditions commonly activated regions of the core brain network. They interpreted this result as supporting the constructive simulation hypothesis, as opposed to the recasting account, insofar as the experimental procedure required episodic recombination of elements into imagined future and past events. Specifically, they suggest that this common activation may reflect the retrieval of episodic contents—a process that is necessary not only when remembering past events, but also when constructing imagined future or past events through a process of recombination.

Importantly, in addition to finding evidence in support of the overlap between remembering and imagining, Addis et al. (2009) found two distinguishable patterns of brain activity within this shared neural network. The spatiotemporal PLS analysis also identified one subsystem within the core brain network that was preferentially associated with the remembering task, and another subsystem preferentially associated with the future and past imagining tasks. However, Addis et al. (2009) did not examine an essential feature of simulations of what may happen in the future and what may have happened in the past: the subjective likelihood of those events. Namely, when prospecting, we usually simulate episodes of what we think is likely or probable to occur to us in the future (Weiler, Suchan, & Daum, 2010). Similarly, we entertain thoughts about alternative past events that we consider more or less likely to have happened. However, as Addis et al. (2009) point out in their discussion, by randomly recombining episodic details taken from multiple memories, participants may have been presented with possible, yet quite unlikely past events that otherwise would have never occurred to them. As such, it remains unclear what are the precise neural mechanisms underlying our capacity to simulate alternative versions of specific past personal episodes that could have happened but did not actually occur—a cognitive process we call *episodic counterfactual thinking* (De Brigard & Giovanello, 2012).

It is worth noting that, although research on the cognitive neuroscience of counterfactual thinking – broadly defined as thoughts of what may have been (Roese, 1997; Byrne, 2002; Epstude & Roese, 2008) – is growing, most studies focus on the simulation of counterfactual alternatives to impersonal events and/or decision-making tasks confined to lab settings, and only a handful have employed stimuli extracted from the participant's own episodic autobiographical recollections. In one such study, De Brigard, Szpunar, and Schacter (in press) asked participants to remember negative, positive, and neutral autobiographical memories, and then simulate self-generated counterfactual alternatives to those memories once or four times. Repeated simulation decreased the perceived plausibility of the episodic counterfactual events. In a neuropsychological study, Beldarrain, Garcia-Monco, Astigarraga, Gonzalez, and Grafman (2005), compared spontaneous versus non-spontaneous generation of episodic counterfactual thoughts in patients with prefrontal damage. Although previous studies of counterfactual thinking have shown that the medial prefrontal and orbitofrontal cortices are critical for counterfactual thinking in decision making tasks (Barbey, Krueger, & Grafman, 2009), Beldarrain et al. (2005) provided evidence to the effect that only spontaneous episodic counterfactual thinking is impaired in patients with prefrontal damage. More recently, Van Hoeck et al., in press; see also Van Hoeck, Ma, Van Overwalle, & Vandekerckhove, 2010), asked participants to either simulate past autobiographical events, possible future events or positive episodic counterfactual thoughts (or "upward counterfactuals", i.e., thoughts about how negative outcomes may have been better) while undergoing fMRI. Their results showed that, when compared with past and future simulations, episodic counterfactual thinking engaged prefrontal, inferior parietal, and left temporal cortices.

The present study contributes to the nascent literature on episodic counterfactual thinking by extending the findings of