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Neural activity associated with repetitive simulation of episodic counterfactual thoughts

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ABSTRACT

When people revisit past autobiographical events they often imagine alternative ways in which such events could have occurred. Often these episodic counterfactual thoughts (eCFT) are momentary and fleeting, but sometimes they are simulated frequently and repeatedly. However, little is known about the neural differences between frequently versus infrequently repeated eCFT. The current study explores this issue. In a three-session study, participants were asked to simulate alternative ways positive, negative, and neutral autobiographical memories could have occurred. Half of these eCFT were repeatedly re-simulated while the other half were not. Immediately after, participants were asked to simulate all these eCFT again while undergoing fMRI. A partial least squares analysis on the resultant fMRI data revealed that eCFT that were not frequently repeated preferentially engaged brain regions including middle (BA 21) and superior temporal gyri (BA 38/39), middle (BA 11) and superior frontal gyri (BA 9), and hippocampus. By contrast, frequently repeated eCFT preferentially engaged regions including medial frontal gyri (BA 10), anterior cingulate cortex, insula, and inferior parietal lobule (BA 40). Direct contrasts for each type of eCFT were also conducted. The results of these analyses suggest differential contributions of regions traditionally associated with eCFT, such as BA 10, anterior cingulate cortex, and hippocampus, as a function of kind of eCFT and frequency of repetition. Consequences for future research on eCFT and rumination are considered.

1. Introduction

When revisiting past autobiographical episodes, we often cannot help but imagine alternative ways in which such events could have occurred. These episodic counterfactual thoughts (eCFT; De Brigard and Giovanello, 2012)—which refer to imagined alternatives to past autobiographical episodes—tend to be distinguished from semantic counterfactual thoughts—imagined alternative ways in which non-personal facts could have been instead (e.g., “what if Iowa City was the capital of the US instead of Washington D.C.”, “what if kangaroos didn’t have tails”; see Roese and Epstude (2017), for a recent characterization). Recent research has shown that these pervasive and generally useful eCFT (Byrne, 2005, 2016; Epstude and Roese, 2008, Roese and Epstude, 2017) tend to engage core regions of the brain's default network (DN; Buckner et al., 2008; Van Hoeck et al., 2013), a set of functionally connected brain regions including ventral medial prefrontal cortex (vMPFC), posterior cingulate cortex (PCC), inferior parietal lobule (IPL), lateral temporal cortex (LTC), dorsal medial prefrontal cortex (dMPFC), and the medial temporal lobes (MTL). Subsequent results refined this initial observation by revealing that not all eCFT engaged DN regions to the same degree. For instance, De Brigard et al. (2013a) showed that eCFT that were judged by participants as being plausible engaged core regions of the DN associated with episodic autobiographical recollection, whereas eCFT participants judged as implausible recruited a significantly different brain pattern. Similarly, it has also been shown that DN is preferentially recruited in eCFT involving people rather than objects, and that this recruitment is modulated both by the familiarity and the similarity of the imagined character relative to the participant (De Brigard et al., 2015). More precisely, when we imagine eCFT featuring people we know and perceive as being similar to us, DN regions are recruited to a greater degree than when we imagine the same eCFT but featuring someone we are neither familiar with nor similar to. Finally, a recent study conducted by Parikh, Ruzic, Stewart, Spreng and De Brigard (in review) also revealed increased recruitment of DN regions for episodic relative to semantic counterfactuals, with perceived plausibility modulating the relative contribution of certain core regions of the DN, such as the hippocampus.

Normally, eCFT tend to be momentary and fleeting. However, in

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some instances, our eCFT are frequently and repeatedly simulated. Indeed, extant evidence suggests that some individuals cannot help but mentally simulate the same counterfactual thought over and over again (Roese et al., 2009). Moreover, for some of them, this repetitive counterfactual rumination—understood as the propensity to entertain repeated, frequent and uncontrollable eCFT—can become dysfunctional and debilitating (Brinker and Dozois, 2009; Tanner et al., 2013). Unfortunately, next to nothing is known about the neural correlates of eCFT that are frequently repeated relative to those that are simulated only infrequently. The current study employs a variation on a previously utilized paradigm (De Brigard et al., 2013b; Szpunar and Schacter, 2013; Szpunar et al., 2015) in an attempt to shed light on this issue. In this three-session study, participants came to the laboratory and provided specific negative, positive, and neutral autobiographical memories. A week later, they returned to generate eCFT based upon their reported episodic autobiographical memories. Specifically, participants were asked to generate upward (i.e., imagined better ways in which past negative events could have occurred), downward (i.e., imagined worse ways in which past positive events could have occurred), and neutral eCFT (i.e., alternative ways in which past neutral events could have occurred without changing the valence of the remembered experience). A day later participants came back for a final, two-part session. In the first part, participants were asked to repeatedly re-simulate half of the counterfactuals they generated. Immediately after, and while undergoing functional magnetic resonance imaging (fMRI), participants were presented with all the previously generated eCFT and were asked, for each of them, whether it had been previously re-simulated or not. As a result, this paradigm allows us to compare brain activity associated with eCFT that were recently repeated versus those that were only simulated once that day.

Two strategies for analyzing the resultant brain data were planned. First, a data-driven spatiotemporal analysis of event-related fMRI data using partial least squares (PLS; McIntosh et al., 2004) was employed to examine whether there were reliable differences in neural activity corresponding to frequently repeated versus non-repeated eCFT. Second, direct contrasts using non-rotated PLS analyses were also planned for each specific direction of eCFT—i.e., upward, downward and neutral—in order to explore differences in brain activity for each kind of eCFT as a function of frequent repetition. Given previous results on repetition-related neural activity in episodic future thinking—a related yet importantly different kind of episodic mental simulation (Schacter et al., 2015, 2017b)—we expected to find more engagement of core regions of the DN for eCFT simulated once relative to eCFT that were repeatedly simulated. This result would be consistent with a prior study, employing a repetition suppression paradigm (Grill-Spector et al., 2006), whereby core areas of DN exhibited neural adaptation as a function of repetition during episodic future thinking (Szpunar et al., 2014). Conversely, for the case of frequently repeated eCFT, we expected to find increased activation in precuneus, middle cingulate cortex, and pIPL, which are the brain areas composing the so-called "parietal memory network" (Gilmore et al., 2015): a functionally defined neural network that reliably shows increments in brain activity as a function of repetition and increased familiarity. Finally, the planned direct contrasts using non-rotated PLS analyses were more exploratory; while we expected to identify regions previously associated with each kind of eCFT (De Brigard et al., 2013a), there being no previous work exploring the effects of repetition on processing of counterfactual thinking, we had no prior hypothesis as to which regions would be more or less active as a function of repetition during downward, neutral or upward eCFT.

2. Materials and methods

2.1. Participants

Twenty-one healthy right-handed English-speaking adults with normal or corrected-to-normal vision and no history of neurological or psychiatric conditions participated in the study. Since two participants failed to complete the second session, data from 19 participants (M_{age} = 22.05, SD = 3.21; 12 females) are included in the analyses. All participants provided written consent in accordance with the guidelines set by the Committee on the Use of Human Subjects in Research at Harvard University and received monetary compensation.

2.2. Pre-scan stimulus collection

In this session, participants were asked to provide 110 autobiographical memories of specific events from their personal past that occurred in the last 10 years. Participants were asked to recall discrete spatiotemporal events that involved either an action they performed or an event that occurred to them, where there was an immediate outcome. For each memory, participants were asked to provide a short description, a title, an approximate date and location, and one person and one object featured in the event. In addition, participants were asked to rate the emotion of each memory from (1) Negative to (5) Positive, with (3) being Neutral. Participants were asked to do their best to retrieve memories corresponding to all three emotions, and were encouraged to try to come up with as many negative, positive and neutral memories as possible. For retrieval support, participants were provided with a list of 100 common events and decisions culled from previous studies (De Brigard et al., 2013a, 2015). An experimenter would check on the participant every hour, verifying that they were providing memories for all emotions. When the participants reached 100 memories, the experimenter will tally the number of negative, neutral and positive memories to verify that there were around 30 memories of each emotion. If there were not enough memories corresponding to one of the emotions, participants would be asked to come up with memories specific to that emotion. The idea was to guarantee that, by the end of the first session, there would be at least 30 memories per emotion. To facilitate adherence to the instructions, participants were provided with examples of negative, positive and neutral specific autobiographical memories. This session took approximately 3 h.

2.3. Counterfactual generation session

One week later, participants returned to the lab to generate eCFT based on the autobiographical memories collected the week before. Specifically, they were asked to generate 30 "upward" counterfactuals from negative memories (i.e., imagine *better* outcomes to events they previously rated as negatively valenced), 30 "downward" counterfactuals from positive memories (i.e., imagine *worse* outcomes to events they previously rated as positively valenced), and 30 neutral counterfactuals from neutral memories (i.e., imagine alternative outcomes that wouldn't have modified the valence of the original memory). Trials were presented randomly on a computer screen, and in each, participants were shown a heading indicating whether the counterfactual they were asked to generate was upward ("positive"), downward ("negative") or neutral ("neutral"). Below, four cues of the original memory were presented: the place, the person, the object and the short title they had provided for the original memory. Participants were required to remember this memory and to think of a relevant counterfactual. Once they had generated the counterfactual, they were asked to press a button that deleted the last cue on the screen (i.e., the title) revealing a text box for them to write a short title for the counterfactual just generated (Fig. 1). Participants were encouraged to do their best to imagine novel counterfactuals. At the end of each trial, participants were asked to rate how sure they were that it was the first time they generated such a counterfactual thought, with (1) being "Not sure" to (5) being "Completely sure." Trials were presented using E-Prime 1.0 (Psychology Software Tools, Pittsburgh PA) on a Dell desktop computer, and participants used the keyboard to type their answers. This session took about 1 h.