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Adaptive constructive processes and memory accuracy: Consequences of counterfactual simulations in young and older adults

Kathy D. Gerlach[1], **David W. Dornblaser**[1], and **Daniel L. Schacter**[1]
[1]Department of Psychology, Harvard University, Cambridge, MA, USA

Abstract

People frequently engage in *counterfactual thinking*: mental simulations of alternative outcomes to past events. Like simulations of future events, counterfactual simulations serve adaptive functions. However, future simulation can also result in various kinds of distortions and has thus been characterized as an *adaptive constructive process*. Here we approach counterfactual thinking as such and examine whether it can distort memory for actual events. In Experiments 1a/b, young and older adults imagined themselves experiencing different scenarios. Participants then imagined the same scenario again, engaged in no further simulation of a scenario, or imagined a counterfactual outcome. On a subsequent recognition test, participants were more likely to make false alarms to counterfactual lures than novel scenarios. Older adults were more prone to these memory errors than younger adults. In Experiment 2, younger and older participants selected and performed different actions, then recalled performing some of those actions, imagined performing alternative actions to some of the selected actions, and did not imagine others. Participants, especially older adults, were more likely to falsely remember counterfactual actions than novel actions as previously performed. The findings suggest that counterfactual thinking can cause source confusion based on internally generated misinformation, consistent with its characterization as an adaptive constructive process.

Keywords

Counterfactual thinking; adaptive processes; episodic memory; false memory; misinformation; aging

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"If only I'd gone to bed earlier last night, I could've woken up on time and wouldn't have had to rush out of the house" describes a scenario many of us have probably envisioned before. People frequently engage in *counterfactual thinking* by flexibly reshaping their memory of past events and constructing mental simulations of how past events might have turned out differently (e.g., Byrne, 2005; Epstude & Roese, 2008; Roese, 1997). Counterfactual thinking can provide a more positive alternative to a past event, referred to as an *upward counterfactual*, such as the above scenario, or it can represent a more negative reality, referred to as a *downward counterfactual* ("If I'd gone to bed even later, I might've slept through my alarm and missed an important appointment"). Counterfactual thinking occurs more often following negative or unusual rather than positive events (Roese & Hur, 1997; Roese & Morrison, 2009): simulations tend to involve idealistic upward rather than downward counterfactuals.

Corresponding Author: Kathy D. Gerlach Harvard University, Department of Psychology 33 Kirkland Street, Cambridge MA 02138 USA p: 617.496.5909, f: 617.496.3122, gerlach@fas.harvard.edu.

Simulating such upward counterfactuals often elicits feelings of disappointment or regret, whereas downward counterfactuals tend to evoke feelings of relative satisfaction or relief by suggesting that a past event could have had a worse outcome (e.g., Roese, 1997; Wrosch, Bauer, & Scheier, 2005). Prevailing functional theories of counterfactual thinking (e.g., Epstude & Roese, 2008; Markman & Mullen, 2005; Roese & Morrison, 2009) posit that its purpose is to prepare us for future actions and goals by way of emotion and behavior regulation that improves future performance (e.g., Ciarocco, Vohs, & Baumeister, 2010; Galinsky & Krey, 2004; Markman, McMullen, & Elizaga, 2008). Upward counterfactual thinking in particular appears to trigger adaptive behaviors by allowing participants to very quickly form intentions for improved future behavior (Smallman & Roese, 2009), which in turn help initiate the desired behavior (Brandstätter, Lengfelder, & Gollwitzer, 2001). Nasco and Marsh (1999) demonstrated this adaptive effect of counterfactual thinking in a study that followed students' performance on an exam: they found that the tendency to generate counterfactuals was positively correlated with students' subsequent performance-enhancing behavior, sense of control, and improved grades.

These adaptive consequences of counterfactual simulations resemble adaptive effects associated with constructing simulations of possible future events. Recent research on the process termed *episodic future thinking* (Atance & O'Neil, 2001) or *episodic simulation* (Schacter, Addis, & Buckner, 2007, 2008) has shown that constructing simulations of experiences that might occur in one's personal future depends on many of the same processes as remembering actual past experiences (for recent reviews, see Schacter, Addis, Hassabis, Martin, Spreng, & Szpunar, 2012; Szpunar, 2010). Such simulations serve a number of useful functions (Schacter, 2012; Suddendorf & Corballis, 2007), including contributing to goal-directed planning (e.g., Gollwitzer, 1999; Spreng, Stevens, Chamberlain, Gilmore, & Schacter, 2010; Taylor, Pham, Rivkin, & Armor, 1998) and problem solving (e.g, Sheldon, McAndrews, & Moscovitch, 2011; Gerlach, Spreng, Gilmore, & Schacter, 2011), enhancing subsequent memory (e.g., Klein, Roberston, & Delton, 2010, 2011; Martin, Schacter, Corballis, & Addis, 2011), promoting farsighted decision making (e.g., Benoit, Gilbert, & Burgress, 2011; Peters & Büchel, 2010), and contributing to psychological well-being (e.g., Brown, MacLeod, Tata, & Goddard, 2002; Sharot, Riccardi, Raio, & Phelps, 2007; Szpunar, Addis, & Schacter, 2012). However, such simulations may also be associated with a variety of pitfalls (Schacter, 2012), including inaccurate predictions of future happiness (Gilbert & Wilson, 2007), instability over time resulting in inflated prediction of the likelihood or plausibility of future events (e.g., Koehler, 1991; Szpunar & Schacter, in press), vulnerability to the planning fallacy (Dunning, 2007), and possible confusions between imagined and actual events (e.g., Garry, Manning, Loftus, & Sherman, 1996; Johnson, 2006; Goff & Roediger, 1998; Loftus, 2003). These considerations led Schacter (2012) to propose that episodic simulation of future events constitutes an adaptive constructive process: it plays a functional role in memory and cognition but creates distortions, biases, or illusions as a consequence of doing so (see also, Bartlett, 1932; Brainerd & Reyna, 2005; Howe, 2011; Johnson & Sherman, 1990; Newman & Lindsay, 2009; Roediger, 1996; Schacter & Addis, 2007; Schacter, Guerin, & St. Jacques, 2011).

Here we suggest that counterfactual thinking – more specifically, *episodic counterfactual thinking* (De Brigard & Giovanello, 2012; De Brigard, Addis, Ford, Schacter, & Giovanello, in press) about specific past personal experiences – can also be viewed as an adaptive constructive process. Like other adaptive constructive processes, episodic counterfactual thinking not only helps cognition and behavior as outlined earlier, but it can also create biases and distortions. Early studies of counterfactual thinking focused on its effect on judgment, demonstrating that the more salient an imagined alternative to a past event was, the more it tended to alter participants' sympathies toward those involved in the event, resulting in biased judgment of their actions (e.g., Gleicher et al., 1990; Kahneman & Tversky, 1982; Macrae, 1992; Miller & McFarland, 1986). In the clinical literature, excessive counterfactual thinking has been linked to increased anxiety and distress (Gilbar & Hevroni, 2007, Markman & McMullen, 2008; Nolen-Hoeksema, 2000).

Although counterfactual thinking is pervasive and seemingly automatically triggered in many everyday situations, its role as an adaptive constructive process has not been examined with regard to memory. For example, it is unclear whether imagining an alternative outcome to a past event could affect a person's memory of the original event by either enhancing the memory of the original event, which is evoked every time a person simulates its counterfactual outcome, or by possibly distorting a person's memory of the original event by rendering the counterfactual outcome more salient. As noted earlier, previous research has shown that imagining novel events can produce memory confusion, leading a person to consider the past occurrence of the simulated event as more likely, or to recollect it as a 'real' memory (e.g., Garry, Manning, Loftus, & Sherman, 1996; Loftus, 2003; Mazzoni & Memon, 2003). If complex events are imagined repeatedly, they tend to be experienced vividly, thus making it difficult to distinguish between memories of real events and imagination (Goff & Roediger, 1998; Johnson, 2006). Such source attribution errors occur when a person remembers an event but either confuses the memory of a simulation with the memory of a real event, or fails to recall the source of the memory entirely.

Even though one recent study found that a specific type of counterfactual thinking, in which participants only focus on an imagined positive alternative irrespective of reality, can lead to an overestimation of past performance in a game of blackjack (Petrocelli & Crysel, 2009), no studies have examined whether episodic counterfactual simulations – that is, counterfactual simulations of the outcomes of specific experiences – can distort episodic memories of those experiences. If episodic counterfactual thinking has an effect on episodic memory, it might function as a form of internally generated misinformation. A large body of research has documented that exposure to misinformation provided by an experimenter can affect memory (Loftus, 2005), ranging from leading questions that create false eyewitness memories (Loftus, 1979) to planting false memories of an event that never occurred using photographs (Schacter, Koutstaal, Johnson, Gross, Angell, 1997). Meade and Roediger (2006) have shown how *self*-generated misinformation on a forced recall test can also lead to false recollection: Participants who guessed words on an initial forced recall test of word lists tended to falsely recollect those guesses as memories of the original material on subsequent tests. In the case of episodic counterfactual thinking, the misinformation could comprise a self-generated alternative outcome to a past event. Counterfactual simulation could render the alternative outcome similarly plausible, elaborate, and available to be retrieved as the original event, which in turn would likely produce confusion between the memory of the original event and the counterfactual event that was simulated after the fact.

However, unlike in typical misinformation paradigms, episodic counterfactual simulations are generated as a direct consequence of an experience, which could tie them to the original experience to such an extent that their memory might automatically evoke the original event, which could prevent any confusion. Constructing counterfactual simulations requires a person to contrast the past event with the counterfactual outcome, thereby underlining their differences and at the same time creating a link between the memory of the original event and the counterfactual. Feelings of regret, disappointment, or relief about the original event that are brought about by the counterfactuals could further improve memory for the original event.

We propose to investigate the effects of episodic counterfactual thinking on memory in both younger and older adults. Older adults often exhibit heightened susceptibility to memory distortions that involve confusion between events that were imagined and events that were perceived or performed (e.g., Hashtroudi, Chrosniak, & Johnson, 1990; McDaniel, Lyle, Butler, & Dornburg, 2008), as well as between perceived events and post-event information (e.g., Jacoby, Bishara, Hessels, & Toth, 2005; Remy, Taconnat, & Isingrini, 2008; Roediger & Geraci, 2007). Compared to younger adults, older adults also appear to be more affected by the aforementioned misinformation effect of self-generated guesses on a word recall test, which were subsequently falsely recalled or recognized as actual memories (Huff, Meade, & Hutchison, 2011; Meade & Roediger, 2006; Meade & Roediger, 2009; Meade, Geraci, & Roediger, 2012). Whether or not this age-related susceptibility to memory distortions applies to counterfactual simulations of past events is unknown, but the aforementioned studies provide grounds for hypothesizing that engaging in episodic counterfactual simulations about how past events might have turned out differently could produce greater memory distortion in older than younger adults.

Examining the effects of episodic counterfactual simulation on memory distortion in both younger and older adults is also of interest in light of the distinction between upward and downward counterfactuals. For instance, negative past events may be perceived as even more negative when people remember them after they have simulated what they should have, yet did not do, during the original event. Downward counterfactual thinking, in contrast, may lead people to judge the emotional valence of a past event to be more positive by emphasizing that “it could have been worse than it was”. Older adults frequently exhibit a positivity effect, remembering relatively more positive information, compared with negative or neutral information, than do younger adults (e.g., Mather & Carstensen, 2005). These observations suggest that older adults may be especially vulnerable to distorting effects of downward counterfactuals, which may enhance positive feelings about the actual event outcome, as compared with upward counterfactuals, which may enhance negative emotions about the outcome of the event. We were particularly interested in these questions involving aging because counterfactual thinking is common across the lifespan (e.g., Epstude & Roese, 2008).

To examine possible effects of counterfactual simulation on episodic memory in both younger and older adults, we developed two novel paradigms that combined new materials with established procedures for testing memory. Experiments 1a and 1b examined counterfactual simulations based on imaginary scenarios, and Experiment 2 examined counterfactual simulations of actions that participants performed in the laboratory.

Experiments 1a/1b

In Experiment 1a, we aimed to approximate real-life experiences and processes of counterfactual thinking in the laboratory while maintaining experimental control. Participants imagined themselves experiencing brief everyday scenarios describing situations with either a positive or a negative outcome that motivated subsequent upward or downward counterfactuals. After this encoding phase, we introduced the critical manipulation: For a subset of the scenarios, participants imagined counterfactual outcomes to previously presented scenarios. For the remaining scenarios, participants either imagined the same scenario again or engaged in no simulation. Following a delay, participants performed a recognition memory test, in which initially experienced scenarios were to be categorized as old, and novel scenarios as well as scenarios that had been simulated as alternatives to initially presented scenarios were to be categorized as new. We hypothesized that if engaging in counterfactual simulations of how past events might have turned out differently distorts memory for the original experience, then participants should be more likely to make false alarms (incorrectly identify new items as old) to counterfactual lures than to novel items.

In Experiment 1b, we altered the scenarios to be more extreme in their emotional valence. Our aim was to test whether effects found in Experiment 1a with less arousing, everyday scenarios extended to more emotionally arousing situations, and to explore whether upward and downward counterfactuals of such situations might differentially affect memory.

Method

Participants—For Experiment 1a, we tested 24 younger adults (15 female; M_{age} = 22 years, SD_{age} = 3.9) between the ages of 18 and 34 and 24 older adults (15 female; M_{age} = 73.5 years, SD_{age} = 6.2) between the ages of 62 and 82. For Experiment 1b, we collected data from 24 younger adults (15 female; M_{age} = 23 years; SD_{age} = 4.4) between the ages of 18 and 34 and from 24 older adults (16 female; M_{age} = 71 years; SD_{age} = 4.7), whose age ranged from 62 to 81 years old. Younger adults were recruited through the Harvard University Psychology Study Pool, and older adults were initially recruited from the Boston area community through flyers, newspaper advertisements, and word of mouth. All older participants were screened for dementia and geriatric depression. Older adults who participated in the experiment scored at least 27/30 on the Mini-Mental State Exam (Folstein, Folstein, & McHugh, 1975), 30/75 on the logical memory score of the Wechsler Memory Scale-III (Wechsler, 1997), and lower than 5/14 on the Geriatric Depression Scale (Scogin, 1987). All participants were native English speakers with normal or corrected-to-normal hearing and vision, had no history of neurological or psychiatric illness, and had at minimum a high-school education. Participants gave informed consent in accordance with the guidelines of the Harvard University Committee on the Use of Human Subjects.

Materials—The stimulus set for Experiment 1a consisted of 120 brief scenarios describing everyday situations, each of which had a version with a more positive and a version with a more negative outcome. For Experiment 1b, these scenarios were altered to be more extreme in their emotional valence (for examples, see Fig. 1A). Emotional valence was validated for both stimulus sets using a 7-point scale that instructed raters to indicate how they felt when they imagined themselves in each scenario (1 = *very bad*, 4 = *neutral*, 7 = *very good*).

The scenarios for both stimulus sets were between 2 to 4 sentences long; positive and negative versions of a scenario were matched in length. All scenarios were read and audio-recorded by a male native speaker of English (audio clips were 8-22 s long) and were presented to participants over headphones (Sennheiser HD 280 Pro). In addition, a conditional clause of the format “If A had/had not happened, then the different outcome B could/would/might have occurred” was recorded for each version of a scenario to be used for the counterfactual manipulation. The alternative outcome (“outcome B”) suggested in the conditional clause always described the opposite-valence version of the scenario (see Fig. 1B).

Each scenario was paired with a postcard-size color photo that applied to both the positive and negative version of the scenario and did not give away the outcome of a scenario. Pictures were selected to represent real-life scenes, which did not contain any people that were actors in a scenario. Only a few pictures had strangers in the background as part of an urban scene. We imposed these criteria onto our set of visual stimuli to facilitate participants’ ability to use each scene as a backdrop for their own imagination and to allow their mental simulations to be as vivid as possible.

Design and Procedure—The overall design corresponded to a 2 (age: young, old) x 2 (valence: positive, negative) x 3 (condition: Identical, Counterfactual, No simulation) mixed factorial, where age was the between-subjects factor and valence and condition were the within-subjects factors.

Encoding phase: The laboratory experiment consisted of a two-phase study period and a subsequent memory test. To ensure that participants understood all instructions and were able to simulate the proposed scenarios for the stipulated period of time, each phase of the experiment was preceded by two practice trials. During the encoding phase of the study period, participants listened to and imagined themselves in all 120 scenarios, which were presented in random order as 5 blocks of 24 scenarios with the same number of positive and negative scenarios per block. Participants were only presented with one version of each scenario; positive and negative versions of a scenario were counterbalanced across participants. While listening to a scenario, participants viewed a related picture to provide them with a visual context for their imagination and to make the encoding phase more salient. To allow equal encoding time for each visual stimulus, pictures remained on screen for 23 s, which exceeded the duration of the longest sound clip by 1 s, and participants were instructed to imagine themselves in the situation for as long as the picture was on the screen.

After viewing a scenario, participants rated how they felt when they imagined themselves experiencing the scenario on a 7-point scale (1 = *very bad*, 4 = *neutral*, 7 = *very good*). They also rated whether they had ever had the same or a very similar experience (1 = *definitely not*, 4 = *undecided*; 7 = *definitely yes*) and how likely they thought it was that they would experience the scenario in the future (1 = *very unlikely*, 4 = *undecided*; 7 = *very likely*). All ratings were self-paced throughout the experiment. It took participants approximately an hour and fifteen minutes to complete the encoding phase; they were allowed to take short breaks between each of the five experimental blocks. At the end of the encoding phase, participants were given 10 min to complete a beginners' Sudoku puzzle as an unrelated distractor task.

Simulation phase: During the subsequent simulation phase, which lasted about 45 min with breaks in between blocks, participants listened to 40 scenarios (20 positive, 20 negative) from the encoding phase (Identical simulation condition) and 40 counterfactual conditionals that were related to scenarios from the encoding phase (Counterfactual simulation condition), which consisted of 20 upward and 20 downward counterfactuals. No pictures were included during the simulation phase. The remaining 40 scenarios from the study phase did not re-appear during the simulation phase (No simulation condition). An equal number of items from the Identical and Counterfactual simulation conditions were presented in random order in 5 blocks of 16 scenarios, and scenarios as well as valence were counterbalanced across conditions and participants. After listening to each scenario, participants were given 7 s to imagine themselves in the already familiar scenario or in the suggested alternative scenario. In the latter case, they heard a conditional clause of the format "If A had/had not happened, then the different outcome B could/would/might have occurred" and were instructed to imagine themselves in the scenario with outcome B. After each simulation period participants provided another valence judgment ("How did you feel when you imagined yourself in the scenario just now?") of the imagined scenario to ensure their attention to the task. They were asked to return to the laboratory approximately 48 hours later to provide more ratings of different scenarios; a 48-hour delay was used in order to avoid the possibility of ceiling effects on the final recognition test.

Recognition memory test: Following this 48-hour delay, participants were given a surprise self-paced recognition memory test of 120 scenarios consisting of 80 previously presented items and 40 items that had not appeared before. Participants made an old/new judgment for each scenario with regard to the encoding phase. They thus indicated whether they had imagined an item at encoding (old), or whether an item was completely novel or had only been imagined as an alternative but had not been presented at encoding (new). If participants decided that an item was old, they subsequently made a source judgment regarding whether the item had only been presented during the study phase (Old-No simulation), presented in both study and simulation phase (Old-Identical simulation), or presented in the study phase but imagined with an alternative outcome in the simulation phase (Old-Counterfactual simulation). If a scenario was rated as new, participants indicated whether it was completely novel (New-New) or whether it had been imagined as an alternative in the simulation phase (New-Counterfactual simulation). There was a "don't remember" option for both old and new source judgments. Participants were also asked to re-rate each scenario on the three scales described in the context of the study phase.

Half of the items on the recognition test were to be categorized as new (60), and the other half was to be categorized as old (60). Critically, 20 items (10 positive, 10 negative) represented counterfactual lures that were to be classified as new. The remaining new items consisted of 40 (20 positive, 20 negative) never-presented, opposite-valence versions of scenarios participants had previously encountered. The old items were made up of 10 positive and 10 negative scenarios from each experimental condition. Scenarios were counterbalanced in such a way that each version of a scenario was shown equally often in each recognition test category across participants. All study materials were administered using MATLAB 7.4 on a Macbook laptop. After concluding the recognition test, participants were debriefed about the experiment.

Statistical analyses—A 2 (age: young, old) x 2 (valence: positive, negative) x 3 (condition: Identical, Counterfactual, No simulation) mixed analysis of variance (ANOVA) scheme was used to investigate differences in hit rate (number of scenarios correctly identified as old/all old items). False alarm rates (false alarms/all new items) were subjected to a 2 (age) x 2 (valence) x 2 (condition: Counterfactual simulation, Baseline) mixed ANOVA. Source identification rates were analyzed for scenarios in the Counterfactual simulation condition using a 2 (age) x 4 (condition: Old-No simulation, Old-Identical simulation, Old-Counterfactual simulation, Old-Don't know) mixed ANOVA in order to examine differences between participants' source judgments of false alarms. A 2 (age) x 3 (condition: New-New, New-Counterfactual simulation, New-Don't know) mixed ANOVA allowed us to compare participants' source identification rates for correctly identified counterfactual lures. All *post-hoc t*-tests were two-tailed and Bonferroni corrected at $\alpha = .05$. Participants' ratings of valence and past and future likelihood of occurrence were compared using Wilcoxon Signed Ranks and Mann-Whitney Tests.

Results

Ratings

Valence: The 100% response rate for behavioral ratings of emotional valence, which we collected after each trial, as well as ratings of past and future likelihood of occurrence, which participants provided after each trial in the encoding phase and the recognition memory test, confirmed that participants complied with the task. Average valence ratings did not differ between young and older participants in Experiment 1a ($U = 270.00$, $p = .71$) or Experiment 1b ($U = 238.00$, $p = .30$; see Table 1). Across age groups, the average emotional valence ratings for each experiment validated our categorization of scenarios as positive and negative; participants' positive and negative ratings differed significantly from each other (Expt. 1a: $Z = -4.29$, $p < .001$; Expt. 1b: $Z = -4.43$, $p < .001$). Scenarios in Experiment 1b were rated as significantly more extreme in emotional valence than those in Experiment 1a (Positive: $U = 197.00$, $p = .06$, Negative: $U = 145.00$, $p = .003$).

Likelihood: Younger and older adults deemed it not unlikely that the presented scenarios happened to them in the past or could happen to them in the future (see Table 1). Young adults tended to rate scenarios as more likely to occur in the future than older adults (Expt. 1a: $U = 141.00$, $p = .002$; Expt. 1b: $U = 176.00$, $p = .02$). Participants' ratings of future likelihood did not differ between experiments (Young: *U* = 263.50, *p* = .61; Older: *U* = 282.50, *p* = .91). Past likelihood ratings were not significantly different between young and older adults (Expt 1a: *U* = 241.00, *p* = .33; Expt. 1b: *U* = 263.50, *p* = .61) and experiments (Young: *U* = 269.00, *p* = .70; Older: *U* = 251.00, *p* = .45). No other differences or effects were significant or consistent across Experiment 1a and 1b.

Memory performance

Hit rates: A 2×2×3 ANOVA of hit rates in Experiment 1a showed a significant interaction effect of age and condition, indicating that participants' hit rates in the three experimental conditions differed depending on their age group ($F(2, 92) = 3.16$, $p < .047$, $\eta^2_p = .06$; see Table 2). *Post-hoc* paired *t*-tests revealed that younger adults showed a significantly higher hit rate in the Identical compared to the No simulation condition, $t(23) = 3.77$, $p < .001$, $d = 0.72$, but that hit rates in the Counterfactual simulation condition differed from neither the No simulation, $t(23) = 1.07$, $p = .30$, $d = 0.23$, nor the Identical simulation condition, $t(23) = 2.16$, $p = .04$, $d = 0.47$. Older adults, whose hit rate was lower than younger adults' across all conditions ($F(1, 46) = 4.04$, $p = .050$, $\eta^2_p = .08$), showed a significant decline in hit rates from the Identical, to the Counterfactual, $t(23) = 3.84$, $p < .001$, $d = 0.98$, and from the Identical to the No simulation condition, $t(23) = 6.08$, $p < .001$, $d = 2.65$. The absence of a similar decline in younger adults' hit rates can likely be explained by a ceiling effect in their performance resulting in scale compression. Besides the main effects of age and condition ($F(2, 92) = 24.56$, $p < .001$; $\eta^2_p = .35$) underlying the interaction, no other factors had any significant effects on hit rates (all Fs ≤ 2.25, $p > .05$).

We observed a similar pattern of results for hit rates in Experiment 1b. A 2×2×3 ANOVA resulted in a significant main effect of condition ($F(2, 92) = 38.23$, $p < .001$, $\eta^2_p = .45$) and of age ($F(1, 46) = 11.77$, $p = .001$, $\eta^2_p = .20$) with significantly decreasing hit rates between the Identical and the Counterfactual simulation condition, $t(23) = 3.64$, $p = .001$, $d = 0.46$, as well as between the Identical and the No simulation condition, $t(23) = 5.57$, $p < .001$, $d = .079$, in older adults, whose hit rates were lower than younger adults' across all conditions. As expected, younger adults exhibited higher hit rates in the Identical compared to the No simulation condition, $t(23) = 5.41$, $p < .001$, $d = 0.93$, but also remembered significantly more items in the Identical relative to the Counterfactual simulation condition, $t(23) = 4.34$, $p < .001$, $d = 0.74$, and in the Counterfactual relative to the No simulation condition, $t(23) = 4.05$, $p < .001$, $d = 0.60$. We also observed a main effect of valence ($F(1, 46) = 4.61$, $p = .04$, $\eta^2_p = .09$): positive scenarios were remembered at a higher rate than negative scenarios across participants and conditions.

False alarm rates: Critically, if counterfactual simulation affects memory for the original experience, then the false alarm rates for counterfactual lures should be significantly higher compared to the false alarm rates for novel scenarios. A 2×2×2 ANOVA for Experiment 1a resulted in a significant main effect of condition on false alarm rate ($F(1, 46) = 32.21$, $p < .001$, $\eta^2_p = .41$), with participants making more false alarms in the Counterfactual simulation condition compared to the Baseline false alarm rate to novel scenarios across both age groups (see Table 2 and Fig. 2). A significant main effect of age revealed that older adults' false alarm rate was significantly higher than younger adults' across both conditions ($F(1, 46) = 11.75$, $p = .001$, $\eta^2_p = .20$). Our analysis also showed an age by condition interaction that approached significance ($F(1, 46) = 3.99$, $p = .052$, $\eta^2_p = .08$). *Post-hoc* paired *t*-tests indicated that the false alarm rate in the Counterfactual simulation condition increased more relative to the Baseline false alarm rate for older than for young adults (Older: $t(23) = 5.17$, $p < .001$, $d = 0.55$; Young: $t(23) = 2.75$, $p = .01$, $d = 0.42$). There was no effect of valence ($F(1, 46) = .33$, $p = .57$, $\eta^2_p = .01$).

The corresponding 2×2×2 ANOVA for Experiment 1b replicated the significant main effect of condition ($F(1, 46) = 24.63$, $p < .001$, $\eta^2_p = .35$) on false alarm rate (see Fig. 3). The main effect of age approached significance ($F(1, 46) = 3.89$, $p = .055$, $\eta^2_p = .08$). *Post-hoc* paired *t*-tests showed that young adults had significantly higher false alarm rates in the Counterfactual simulation compared to the Baseline condition, $t(23) = 3.35$, $p = .003$, $d =$ 0.10. The same pattern of results applied to older adults, $t(23) = 4.49$, $p < .001$, $d = 0.78$. Once again, valence did not affect false alarm rates ($F(1, 46) = .32$, $p = .58$, $\eta^2_p = .01$).

Source identification rates: The 2×4 ANOVA of participants' source identification rates of false alarms in response to counterfactual lures in Experiment 1a yielded a significant interaction effect of age and condition ($F(3, 138) = 9.50$, $p < .001$, $\eta^2_p = .17$; see Table 3). *Post-hoc* pairwise *t*-tests revealed that false alarms were most often made due to young participants identifying a counterfactual lure as a scenario they had encountered at encoding and for which they had also subsequently imagined a counterfactual outcome, instead of a scenario that was only presented at encoding, $t(23) = 2.78$, $p < .001$, $d = 1.43$, a scenario that was presented during both the encoding and the simulation phase, $t(23) =3.72$, $p < .001$, $d =$ 1.60, or a scenario whose source they did not recall, t(23) = 2.82, p < .001, $d = 1.33$. Even though older adults also displayed the highest source identification rate for the Old-Counterfactual simulation condition, it did not significantly differ from the Old-No simulation, $t(23) = 1.66$, $p = .005$ $d = 0.74$, or the Old-Identical simulation condition, $t(23) =$ 1.40, $p = .06$, $d = 0.56$, though it was significantly different from the "don't know" condition, $t(23) = 3.44$, $p < .001$, $d = 1.24$.

We found an analogous pattern of results for the ANOVA in Experiment 1b, which also resulted in a significant age by condition interaction ($F(3, 138) = 7.56$, $p < .001$, $\eta^2_p = .13$). Young adults tended to be more likely to incorrectly recall the source of a counterfactual lure to be a scenario they initially encoded and subsequently simulated counterfactually than a scenario they only encountered at encoding, $t(23) = 2.35$, $p < .001$, $d = 1.52$, a scenario they encountered in the same form during the encoding and the simulation phase, $t(23) =$ 2.84, $p < .001$, $d = 2.21$, or a scenario of which they lacked source knowledge, $t(23) = 3.03$, $p < .001$, $d = 2.54$. Older adults' source identification rates were much more evenly spread out between the Old-Counterfactual simulation and the Old-Identical simulation condition, $t(23) = .84$, p = .71. $d = 0.07$, as well as the Old-Counterfactual and the Old-No simulation condition, $t(23)= 1.13$, p = .50, $d = 0.25$, though the counterfactual rates were significantly different from the "don't know" option, $t(23) = 4.25$, $p < .001$, $d = 1.42$.

Counterfactual lures that were correctly identified as new in Experiment 1a showed a significant age by condition interaction for their source identification rates ($F(2, 92) = 9.44$, $p < .001$, $\eta^2_p = .17$). *Post-hoc t*-tests revealed that young participants were able to correctly identify the source of most counterfactual lures instead of categorizing them as completely novel scenarios, $t(23) = 3.52$, $p = .002$, $d = 1.41$, or indicating their lack of source memory, $t(23) = 7.27$, $p < .001$, $d = 0.48$. In contrast, older adults' source identification rates did not differ significantly between their categorization of counterfactual lures as completely novel and as having been imagined as an alternative, $t(23) = 1.24$, $p = .23$ $d = 0.50$, and between the latter and the "don't know" option, $t(23) = 2.41$, $p = .03$, $d = 0.77$.

Experiment 1b replicated the significant interaction effect of condition and age for correctly identified counterfactual lures ($F(2, 92) = 8.47$, $p < .001$, $\eta^2_p = .16$). Young adults in this experiment were also significantly more likely to remember the correct source of a counterfactual lure instead of classifying a it as novel scenario, $t(23) = 4.50$, $p < .001$, $d =$ 1.72, or admitting to not remembering the source, $t(23) = 9.31$, $p < .001$, $d = 3.24$. Again, older adults' source identification rates did not differ between the correct New-Counterfactual simulation and the New-New condition, $t(23) = 0.49$, $p = .63$, $d = 0.22$.

Discussion

Experiments 1a and 1b both revealed that participants made false alarms in response to counterfactual lures above and beyond novel items, indicating that counterfactual simulation distorted their memory of the original event, and that the effect applies both to everyday scenarios of relatively low and high emotional valence. The distorting effect of counterfactual simulations was more pronounced in older adults, confirming previous findings of older adults' increased susceptibility to memory distortions in related paradigms (e.g., Hashtroudi et al., 1990; Jacoby et al., 2005; McDaniel et al., 2008; Remy et al., 2008; Roediger & Geraci, 2007; Schacter et al., 1997). False alarms were most often due to participants identifying a counterfactual lure as having been encountered at encoding, thereby making a source attribution error and confusing the memory of the counterfactual simulation with the memory of the original event. Unlike younger adults, older adults were close to chance with their source judgments between the three experimental conditions. When participants correctly identified counterfactual lures as new, only young adults were able to make correct source judgments about them. Older adults, in turn, classified approximately half of the counterfactual lures as entirely novel scenarios, indicating that they had forgotten the previous counterfactual simulation, which may have protected them from making even more false alarms.

Valence did not seem to play a role in counterfactual memory distortions, even for older adults. One possibility is that upward and downward counterfactual lures do not differentially affect memory for a scenario. In addition, the positivity effect previously observed in older adults may not apply in this context. Alternatively, it could be that upward and downward counterfactuals need to be simulated for actual experiences, as opposed to the hypothetical scenarios we used, in order to show any difference. To test whether the findings of Experiments 1a and 1b extend to performed actions and whether we could replicate our results with very different materials, Experiment 2 examined the effects of counterfactual simulations on actions performed in the laboratory.

Experiment 2

In Experiment 2, participants were asked to perform actions and were rewarded for half of them in order to create positive and negative experiences. These experiences set the stage for upward counterfactual simulations of the action a participant should have performed instead in order to obtain the reward, and downward counterfactual simulations of the action a participant would have performed had they not selected the rewarded action. The reward system used in the experiment was based on a cover story, according to which participants were supposed to choose and perform the action of a pair of actions that had been shown to be the more popular of the two in previous experiments. The remaining overall design of this experiment was similar to that of Experiments 1a/b, in that the performed actions were recalled, simulated counterfactually, or not at all presented during a simulation phase, which followed an encoding phase and preceded a delayed old/new recognition memory test. The critical questions were whether counterfactual lures would again elicit false alarms in our participant groups, would do so to a greater extent in older adults, and whether any differences between upward and downward counterfactuals would emerge using our task involving performed actions.

Method

Participants—24 young adults (13 female; M_{age} = 22 years, SD_{age} = 2.5) between 18 and 29 years of age and 24 older adults (13 female; M_{age}= 75 years, SD_{age} = 8.2) between 60 and 93 years old gave informed consent to participate in this experiment according to the same criteria as in Experiment 1.

Materials—The stimuli for Experiment 2 comprised 50 pairs of actions adapted from McDaniel et al. (2008), such as chaining paper clips in a line (action A) or a circle (action B) or clapping one's hands together (action A) or snapping one's fingers (action B; see Supplementary Material). 25 action pairs involved objects; the remaining 25 required physical gestures.

Design and Procedure—The main design consisted of a 2 (age) x 2 (valence) x 3 (condition) mixed factorial with valence and condition as within-subject factors and age as the between-subject factor.

Encoding phase: Experiment 2 was structured very similarly to Experiments 1a/b: Participants engaged in a two-phase study period divided by a 10min distractor task and completed a surprise recognition memory test one week after the encoding and simulation phases. During the encoding phase, participants were presented with 40 pairs of actions and were asked to choose the action of each pair that they considered the more popular choice. As the cover story for the reward system in this experiment, participants were told that a previous study had identified the action of each action pair that most people preferred to perform, and that their task was to correctly choose said action in order to receive a 10-cent reward. Each trial was pre-determined to result in a 10-cent reward or no reward, which was counterbalanced across participants, with 50% of trials yielding a reward. After choosing an action, participants were informed whether or not they received a reward for their choice and subsequently performed the chosen action.

Simulation phase: Following a 10-min unrelated distractor task (beginners' Sudoku), participants were asked to imagine 30 actions in three distinct ways. They recalled performing 10 actions (5 rewarded, 5 unrewarded) from the encoding phase (Recall condition), they imagined performing the rewarded, previously *not* chosen action of 10 action pairs (Upward counterfactual simulation condition), and they imagined performing the unrewarded, previously *not* chosen action of another 10 action pairs (Downward counterfactual simulation condition). These simulations were administered in random order and were repeated three times for each action. 10 out of the 40 action pairs from the encoding phase were not presented in any way during this study phase (No simulation condition). All actions were counterbalanced in such a way that each action was shown equally often in each condition across participants.

Recognition memory test: One week later, participants completed a paper-and-pencil surprise recognition memory test. Of the 100 actions on the test, participants had viewed 80 during the encoding phase (and chosen 40), and 20 actions were completely novel. They were to indicate that an action was *old* if they had performed it during the encoding phase, and that an action was *new* if they had not performed it during the encoding phase (i.e., it was completely novel or represented an alternative action they had not been chosen in the encoding phase). All participants were debriefed about the experiment.

Statistical analyses—In order to examine differences in hit rates as well as false alarm rates, we conducted 2 (age) x 2 (valence) x 3 (condition) mixed ANOVAs with valence and condition as within-subject factors and age as the between-subject factor. All *post-hoc t*-tests were two-tailed and Bonferroni corrected at $\alpha = .05$.

Results

Memory performance

Hit rates: A 2×2×3 ANOVA of hit rates resulted in a significant interaction of age by valence by condition ($F(2, 92) = 4.75$, $p = .01$, $\eta^2_p = .09$), with older adults producing significantly lower hit rates across conditions and valence compared to younger adults (F(1, 46) = 8.98, p = .004; η^2_p = 0.16; see Table 4). *Post-hoc* paired *t*-tests showed that older adults correctly remembered more rewarded tasks from the Recall condition than the No simulation condition, $t(23) = 4.52$, $p < .001$, $d = 1.05$, as well as more rewarded tasks from the Downward counterfactual simulation than the No simulation condition, $t(23) = 3.86$, $p < .001$, $d = 1.03$.

False alarm rates: Importantly, participants made false alarms to 1) items that had been viewed but not selected during the encoding phase of the Recall condition, 2) items that had been viewed but not selected during the encoding phase of the No simulation condition, 3) items that had been simulated as counterfactuals, and 4) items that were completely novel. A 2×2×3 ANOVA of false alarm rates in conditions 1) through 3), which included rewarded and unrewarded trials at encoding, yielded no significant age by valence by condition interaction, valence by condition interaction, or main effects of valence (all *F*s ≤ 1.23, $p \geq .29$). We further determined that there was no difference between false alarm rates in response to previously non-selected items in the Recall and No simulation conditions in either age group (Young: $t(23) = 0.18$, $p = .86$, d = 0.09; Older: $t(23) = 1.15$, $p = .26$, $d = 0.20$) and thus combined the false alarm rates from both conditions to form a Control condition. A 2×3 ANOVA comparing false alarm rates in the Counterfactual simulation, Control, and Novel conditions yielded a significant age by condition interaction ($F(2, 92) = 5.94$ $p = .004$, $\eta^2_p = .11$; see Table 4 and Fig. 3). *Post-hoc* independent *t*-tests indicated that the extent to which older adults made more false alarms than younger adults was higher in the Counterfactual simulation and Control condition than in the Novel condition (Counterfactual: $t(46) = 4.51$, $p < .001$, $d = 1.27$; Control: $t(46) =4.30$, $p < .001$, $d = 1.20$; Novel: $t(46) = 3.10$, $p = .003$, $d = 0.85$). There was also a significant counterfactual simulation effect in young adults, who produced more false alarms in response to Counterfactual simulations than items in the Control, $t(23) = 3.16$, $p = .004$, $d = 0.69$, or Novel condition $t(23) = 6.42$, $p < .001$, $d = 1.74$.

Discussion

Experiment 2, which was based on performing real actions at encoding, yielded even more pronounced effects of counterfactual thinking on memory than did Experiments 1a and 1b. Older adults made false alarms in response to counterfactual lures to a greater extent than younger adults, producing a false alarm rate that exceeded those in Experiments 1a and 1b.. Critically, both age groups' false alarm rates in response to counterfactual lures were not only significantly higher relative to their false alarm rates in response to entirely novel actions, but also surpassed false alarm rates in response to lures of actions that had been viewed and considered, but had not been chosen and performed at encoding. This finding serves to emphasize the role of *simulation* – as opposed to mere exposure to an alternative – in the memory distortion observed here. Analogous to Experiments 1a/b, participants had similarly high false alarm rates in response to counterfactual lures whether their counterfactual simulation had been upward or downward. Experiment 2 also replicated the general pattern of hit rates found in the previous experiments, which declined slightly between the Recall, Counterfactual, and No simulation conditions.

Summary and Concluding Discussion

Our experiments revealed, for the first time, that episodic counterfactual thinking can affect memory for past events, and can do so to a greater extent in older than in young adults. Even though people frequently engage in counterfactual thinking in everyday life, and even though it has been investigated in the context of a number of other cognitive domains, no prior research had examined whether simulating an alternative past event could affect a person's memory of the original event. Experiment 1a used everyday scenarios in which participants could envision themselves in order to create experiences to which they subsequently imagined alternative outcomes. In a recognition memory test participants falsely recognized counterfactual scenarios as originally presented scenarios and also did so when we used scenarios of more extreme valence in Experiment 1b. Experiment 2 replicated Experiment 1a and 1b's findings of counterfactual simulation effects on memory using very different materials and asking participants to perform actions in the laboratory.

These findings are consistent with our hypothesis that episodic counterfactual simulations can serve as a form of internally generated misinformation (Loftus, 2005). While previous research on misinformation has shown memory distortions after introducing external misinformation, counterfactual simulations in real life are triggered automatically and internally. In response to an experience, we can fabricate counterfactual misinformation ourselves by constructing and envisioning an alternative to the original experience. Related research has already shown that the act of simulation can elicit memory confusion, which can cause a person to falsely recollect imagined novel events as real memories (e.g., Garry et al., 1996; Loftus, 2003; Mazzoni & Memon, 2003). However, it was previously unclear whether episodic counterfactual simulations could have effects on memory similar to misinformation or imagination inflation, as counterfactual simulations are by definition tied to the factual past event. The way in which counterfactuals are typically imagined directly highlights the discrepancy between the actual and the counterfactual outcome: If outcome A had not occurred, outcome B could have occurred instead. This contrasting link between the original outcome and the counterfactual outcome could have decreased participants' vulnerability to memory errors and instead strengthened memory accuracy for the original event.

In the current paradigms we asked participants to engage in vivid simulations of alternative scenarios or actions, which seems to in some cases have rendered the alternative simulation as memorable as the original event. Our source attribution findings from Experiment 1a/b confirmed that participants tended to misremember the source of their recognition memory when making false alarms. We therefore suggest that episodic counterfactual simulations can act as a kind of internally generated misinformation that can cause source confusion, in line with findings and ideas from previous research reported in the classic misinformation paradigm (e.g., Higham, Luna, & Bloomfield, 2011; Lindsay, 1990; Loftus, 2005; Zaragoza & Lane, 1994). While the misinformation in our experiments was internally generated, we did provide participants with the contents of their counterfactual simulations. Spontaneously self-generated and possibly repeated episodic counterfactual simulations in real life may be even more powerful at rendering the alternative simulation as memorable as or possibly more memorable than the original event.

Even though people typically produce upward counterfactuals more often than downward counterfactuals (Summerville & Roese, 2008), and even though, as we discussed in the introduction, upward and downward counterfactuals have differential effects on emotion regulation and goal-directed behavior (Epstude & Roese, 2008), our findings provide no evidence that valence plays a role in the effect of episodic counterfactual simulations on memory in younger or older adults. Although, as noted earlier, older adults often exhibit a positivity bias (Mather & Carstensen, 2005), which led us to suggest that they might be especially prone to distorting effects of downward counterfactuals, the positivity bias is not observed across all tasks and situations (e.g., Gruhn, Smith, & Baltes 2005; Kensinger, Garoff-Eaton, & Schacter, 2007; Kensinger & Schacter, 2008). Thus one possibility is that an age-related positivity bias does not extend to the domain of counterfactual simulation. Another possibility is that the constructs of upward and downward counterfactuals do not map in any simple or direct way onto to the constructs of negative and positive information as studied in the cognitive aging literature. Finally, it is possible that differential effects of upward and downward counterfactuals might only be observed for real-life experiences that are highly meaningful to participants. Future research that explores whether counterfactual simulations can affect everyday autobiographical memory would be well positioned to determine whether a distinction between the effects of upward and downward counterfactuals can be observed in either young or older adults.

Our experiments represent only a beginning attempt to examine the effects of episodic counterfactual simulation on memory and to contribute to the discussion of counterfactual thinking as a specific type of adaptive constructive process. The role of counterfactual simulations in creating memory confusion fits with the general notion discussed earlier that some adaptive processes that enhance the efficient operation of memory and cognition also create distortions as a result of doing so (e.g., Bartlett, 1932; Brainerd & Reyna, 2005; Howe, 2011; Johnson & Sherman, 1990; Newman & Lindsay, 2009; Roediger, 1996; Schacter, 2012; Schacter & Addis, 2007; Schacter et al., 2011). However, based on the lack of valence effects in the current results, there does not seem to be a direct relationship between the proposed functionality of counterfactuals and the likelihood of counterfactuals to create memory confusion. If upward counterfactuals prepare a person for similar future scenarios, being more likely to remember the more successful way of action as part of the upward counterfactual would be more adaptive than remembering a downward counterfactual outcome, which would stand in the way of emotion regulation. Further research should examine whether upward and downward counterfactuals in response to meaningful real-life events show a differential likelihood to cause memory confusion.

Real-life counterfactual thinking in response to very salient past events may occur repeatedly, which could decrease the likelihood of memory confusion and render counterfactual simulations more functional, as long as they are not repeated excessively. There was no difference in the extent to which participants' memory was distorted between Experiment 1, which required one counterfactual simulation per trial, and Experiment 2, which required three repeated simulations (but also contained very different materials than Experiment 1). However, recent research on the effects of repeated imagining on the perceived plausibility of episodic counterfactual simulations has found that perceived plausibility decreases with repeated simulations across upward and downward counterfactuals (De Brigard, Szpunar, & Schacter, in press). This finding could have implications for understanding memory for episodic counterfactual simulations that should be investigated: While repeated counterfactual simulations should render counterfactuals more memorable, decreased perceived plausibility may counteract any memory confusion.

Finally, the effect of counterfactual simulations on memory should also be considered in light of less common responses to counterfactual simulations (Markman & McMullen, 2005): Instead of generating a sense of relief, simulating downward counterfactuals can sometimes trigger feelings of fear or guilt. Upward counterfactuals, in turn, can bring about positive feelings ("I almost won the race and am likely to win next time") instead of regret or disappointment. Taking into account these finer distinctions between affective responses to counterfactual simulations, as well as other features of everyday counterfactual simulations, such as perceived plausibility and meaningfulness, should increase our understanding of how and when counterfactual thinking helps coordinate cognitive processes such as memory, and how, when, and why it may result in error or illusion.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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	Experiment 1a		**Experiment 1b**	
A.	**Positive**	**Negative**	**Positive**	**Negative**
Encoding	"You're at a nearby furniture store to buy a new chair for your kitchen table to replace a chair whose leg broke. You measured the height of your table and find a chair whose design fits in well enough and whose height matches the table. You carry it home and replace the broken chair with it."	"You're at a nearby furniture store to buy a new chair for your kitchen table to replace a chair whose leg broke. You don't quite remember how high your kitchen table is but buy a chair whose design seems to fit perfectly. When you get home, you find that the chair is too high for your table."	"You're at a furniture store that's an hour away to buy a new chair for your kitchen table to replace a chair whose leg broke. You measured the height of your table and find a chair you think fits well. The chair even turns out to be on sale, and you come back home to find that the chair matches the table and the other chairs perfectly."	"You're at a furniture store that's an hour away to buy a new chair for your kitchen table to replace a chair whose leg broke. You don't quite remember how high your kitchen table is but buy a chair you think fits well. When you get home after an hour drive, you try it out to find that it's too high and that its back and two legs are loose."
B. Imagination	**Downward Counterfactual**	**Upward Counterfactual**	**Downward Counterfactual**	**Upward Counterfactual**
	"If you hadn't measured the height of your kitchen table when buying a new chair, you could've found a chair whose design fit perfectly, but when you got home, you might've found out that the chair was too high for the table."	"If you'd measured your kitchen table before buying a new chair at the furniture store, you could've found a chair whose design and height matched the table better. You would've carried it home and replaced the broken chair."	"If you hadn't measured the height of the table to make sure the new chair matched in size, you could've driven an hour back home. When you tried it out, you could've found that the new chair was too high and that its back and two legs were loose.	"If you'd measured the height of your table before driving an hour to the furniture store, you could've found a fitting, functional chair. It might've even been on sale, and you could've come back home with a perfectly matching chair.

Figure 1.

A. Examples of positive and negative versions of a scenario presented during the encoding phase in Experiments 1a and 1b. B. Examples of upward and downward counterfactuals derived from the scenarios in A. that are presented during the simulation phase in Experiments 1a and 1b.

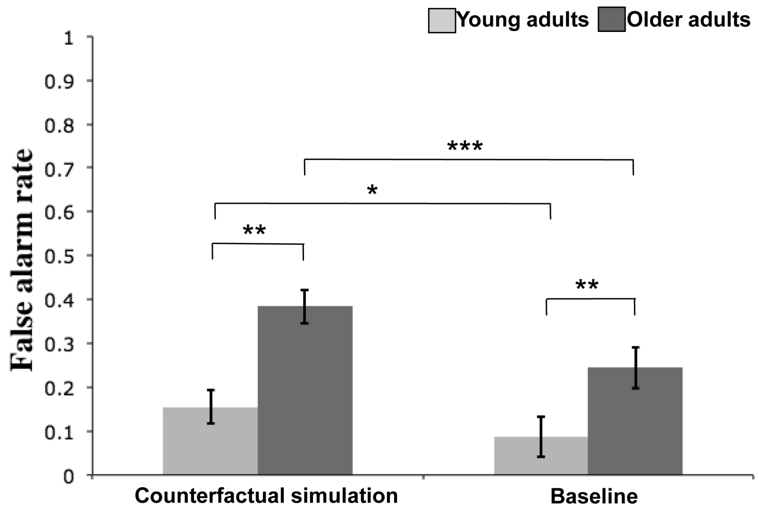

Figure 2.

False alarm rates in response to counterfactual lures (Counterfactual simulation) and novel items (Baseline) for Experiment 1a showing a trending age by condition interaction ($F(1,46) = 3.99$, $p = .052$). *Post-hoc t*-tests were Bonferroni corrected, *$p < .05$, two-tailed. Error bars represent standard errors of the mean.

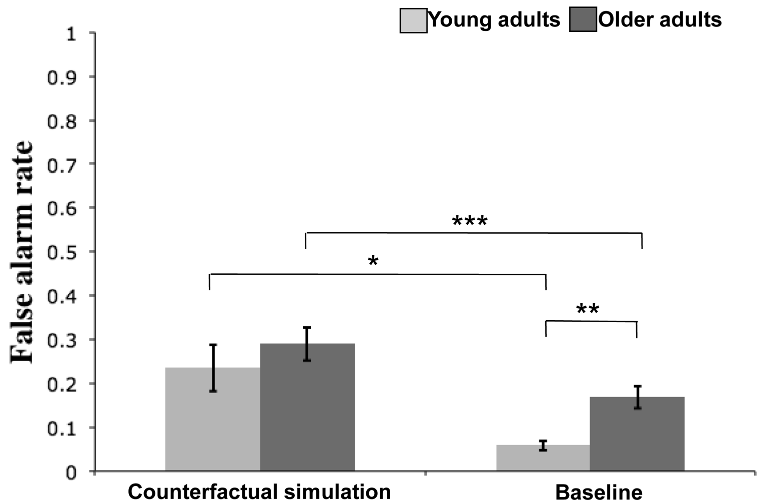

Figure 3.

False alarm rates in response to counterfactual lures (Counterfactual simulation) and novel items (Baseline) for Experiment 1b showing significant main effect of condition (F(1,46) = 24.63, $p < .001$) and a main effect of age approaching significance ($F(1,46) = 3.89$, $p = .055$). *Post-hoc t*-tests were Bonferroni corrected, *$p < .05$, two-tailed. Error bars represent standard errors of the mean.

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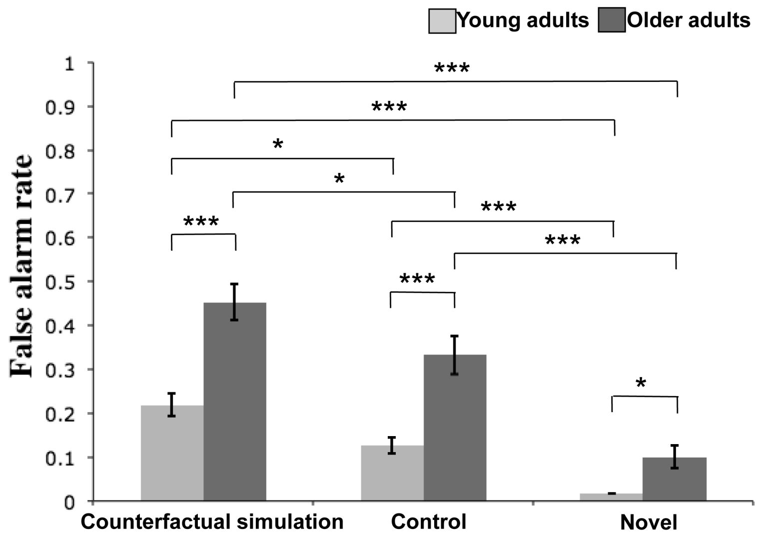

Figure 4.

False alarm rates in response to counterfactual lures (Counterfactual simulation), actions that were viewed but not performed at encoding (Control), and novel items (Novel) for Experiment 2 showing a significant age by condition interaction ($F(2,45) = 4.98$; $p < .05$). *Posthoc* t-tests were Bonferroni corrected, *$p < .05$, two-tailed. Error bars represent standard errors of the mean.

Table 1

Expt 1a/b ratings characteristics

		Young adults			Older adults			Across ages	
		Positive scenarios	Negative scenarios	Across valence	Positive scenarios	Negative scenarios	Across valence	Positive scenarios	Negative scenarios
Measure	**Experiment**	**M (SD)**	**M (SD)**	**M (SD)**	**M (SD)**	**M (SD)**	**M (SD)**	**M (SD)**	**M (SD)**
Valence	1a	5.66 (0.52)	2.52 (0.55)	4.09 (0.26)	5.74 (0.49)	2.46 (0.66)	4.10 (0.39)	5.70 (0.33)	2.49 (0.41)
	1b	5.75 (0.39)	2.33 (0.92)	4.04 (0.51)	6.13 (0.47)	2.12 (0.96)	4.12 (0.43)	5.94 (0.32)	2.23 (0.71)
Past likelihood	1a	4.57 (0.84)	3.93 (0.98)	4.25 (0.82)	4.92 (0.64)	4.01 (0.83)	4.46 (0.67)	4.74 (0.58)	3.97 (0.72)
	1b	4.46 (0.79)	3.79 (0.86)	4.12 (0.74)	4.67 (0.98)	3.78 (1.15)	4.23 (1.02)	4.57 (0.60)	3.78 (0.56)
Future likelihood	1a	4.83 (0.71)	3.93 (0.95)	4.38 (0.76)	4.28 (0.99)	3.00 (0.85)	3.64 (0.86)	4.56 (0.60)	3.47 (0.62)
	1b	4.73 (0.71)	3.74 (0.88)	4.24 (0.67)	4.27 (0.96)	3.12 (1.12)	3.69 (0.97)	4.50 (0.59)	3.43 (0.60)

Note: Valence (positive/negative) refers to the first presentation of the scenario

Table 2

Expt 1a/b memory performance characteristics

		Expt 1a		Expt 1b	
		Young adults	Older adults	Young adults	Older adults
Measure	Condition	M (SD)	M (SD)	M (SD)	M (SD)
Hit rate	Identical	0.94 (0.08)	0.92 (0.08)	0.93 (0.09)	0.80 (0.22)
	Counterfactual	0.89 (0.13)	0.83 (0.12)	0.89 (0.11)	0.69 (0.26)
	No simulation	0.86 (0.13)	0.76 (0.15)	0.82 (0.14)	0.61 (0.26)
False alarm rate	Baseline	0.09 (0.11)	0.24 (0.24)	0.06 (0.05)	0.17 (0.12)
	Counterfactual	0.15 (0.17)	0.38 (0.27)	0.24 (0.26)	0.29 (0.18)

Table 3

Expt 1a/b source memory performance characteristics in response to counterfactual lures

		Expt 1a		Expt 1b	
		Young adults	Older adults	Young adults	Older adults
Measure	Source condition	M (SD)	M (SD)	M (SD)	M (SD)
False alarm rate	Old-Identical simulation	0.11 (0.21)	0.27 (0.27)	0.08 (0.16)	0.34 (0.26)
	Old-Counterfactual simulation	0.60 (0.38)	0.44 (0.33)	0.71 (0.37)	0.36 (0.32)
	Old-No simulation	0.14 (0.25)	0.22 (0.26)	0.17 (0.31)	0.28 (0.33)
	Old-Don’t know	0.15 (0.29)	0.06 (0.28)	0.04 (0.05)	0.01 (0.14)
Correct source identification rate	New-Counterfactual simulation	0.68 (0.33)	0.35 (0.36)	0.69 (0.27)	0.45 (0.33)
	New-New	0.26 (0.26)	0.52 (0.32)	0.25 (0.24)	0.52 (0.32)
	New-Don’t know	0.06 (0.11)	0.13 (0.18)	0.03 (0.10)	0.03 (0.05)

Table 4

Expt 2 memory performance characteristics

Measure	Condition	Valence	Young adults M (SD)	Older adults M (SD)
Hit rate	Identical	Rewarded	0.85 (0.18)	0.81 (0.18)
		Unrewarded	0.86 (0.19)	0.69 (0.29)
	Counterfactual	Downward	0.80 (0.18)	0.77 (0.09)
		Upward	0.80 (0.17)	0.66 (0.18)
	No simulation	Rewarded	0.79 (0.22)	0.61 (0.20)
		Unrewarded	0.66 (0.23)	0.58 (0.28)
False alarm rate	Counterfactual		0.22 (0.16)	0.45 (0.20)
	Control		0.13 (0.09)	0.33 (0.21)
	Recall		0.13 (0.12)	0.36 (0.29)
	No simulation		0.13 (0.10)	0.31 (0.19)
	Novel		0.02 (0.03)	0.10 (0.13)

Note: False alarm rates for the Recall and No simulation condition were combined in the Control condition