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On the adaptive function of children's and adults' false memories

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ABSTRACT

Recent research has shown that memory illusions can successfully prime both children's and adults' performance on complex, insight-based problems (compound remote associates tasks or CRATs). The current research aimed to clarify the locus of these priming effects. Like before, Deese–Roediger–McDermott (DRM) lists were selected to prime subsequent CRATs such that the critical lures were also the solution words to a subset of the CRATs participants attempted to solve. Unique to the present research, recognition memory tests were used and participants were either primed during the list study phase, during the memory test phase, or both. Across two experiments, primed problems were solved more frequently and significantly faster than unprimed problems. Moreover, when participants were primed during the list study phase, subsequent solution times and rates were considerably superior to those produced by those participants who were simply primed at test. Together, these are the first results to show that false-memory priming during encoding facilitates problem-solving in both children and adults.

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Memory is renowned for being fallible. Errors of commission, or falsely "remembering" information that was never experienced, are among the most frequently encountered memory problems (e.g., Brainerd, Reyna, & Zember, 2011; Gallo, 2010; Howe, Wimmer, Gagnon, & Plumpton, 2009; Roediger, 1996). To study these errors, researchers have turned to the Deese–Roediger–McDermott (DRM) paradigm (Deese, 1959; Roediger & McDermott, 1995). Here, participants are presented with a list of words (e.g., *nurse, medicine, hospital*) that are all associates of a nonpresented but related concept, known as the critical lure (e.g., *DOCTOR*). Research using this paradigm has found that: (1) in subsequent recall and recognition tests participants frequently yet incorrectly identify the nonpresented critical lure as having been present in the previously studied list, and (2) developmentally, younger children exhibit fewer false memories compared with older children and adults (e.g., Brainerd et al., 2011; Gallo, 2010; Howe et al., 2009).

False memory illusions, including those produced by the DRM paradigm, are frequently viewed as being a negative consequence of a powerful, reconstructive memory system. These negative consequences are not simply limited to misremembering items on lists, but extend to falsely remembering event-consistent objects or people that were not present during the original experience. In extreme examples, people incorrectly recount earlier experiences as ones that they believed happened (e.g., being abducted by a UFO) when in fact no such event occurred (e.g., Otgaar, Candel, Merckelbach, & Wade, 2009). Worse, such false memories can have serious personal costs, as in cases involving false accusations of sexual assault that lead to the conviction of innocent people (e.g., Howe, 2013).

However, some recent research has suggested that there may be more positive consequences of false memory illusions (e.g., Howe, 2011; Howe & Derbish, 2010). What such studies have found is that false memories can and do behave in similar ways to true memories. For example, McDermott (1997) and McKone and Murphy (2000) showed that false memories generated using the DRM paradigm could prime performance on related memory tasks using both implicit (e.g., stem completion) and explicit (e.g., stem-cued recall) memory measures. Similar effects with fragment completion have been obtained with children (Diliberto-Macaluso, 2005). These parallels prompted researchers to examine the possible beneficial effects false memories could have on other memory tasks, with the positive consequences of memory illusions quickly becoming apparent (for reviews, see Howe, 2011; Schacter, Guerin, & St. Jacques, 2011).

Importantly, if false memories have positive consequences similar to those normally ascribed to true memories, then we should see these consequences across a variety of cognitive domains and not simply in other memory tasks. One cognitive domain in which memory processes may play a key, supporting role is problem-solving. Historically,

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the dependence of problem-solving on memory has been hotly debated (e.g., see Brainerd & Reyna, 1993, for claims regarding independence, and Howe, Rabinowitz, & Grant, 1993, for an opposing position). The emerging consensus, however, is that successful problem-solving is crucially *dependent* on a range of memory processes, including the recall of knowledge acquired through instruction and worked examples (e.g., Nokes & Ohlsson, 2005; Renkl, 2002), the application of a "recognition heuristic" that can provide valid cues in decision-making (e.g., Goldstein & Gigerenzer, 2002; Kahneman & Klein, 2009; Oppenheimer, 2003), and the transfer of analogous experiences to assist in attaining current goals (e.g., Bassok & Holyoak, 1989; Richland, Zur, & Holyoak, 2007).

Although these latter memory processes appear to rely largely on direct or explicit retrieval there is also increasing acknowledgement that memory can influence problem-solving and reasoning through intuitive processes operating indirectly or implicitly (e.g., Evans, 2011; Stanovich, West, & Toplak, 2011). Such intuitive processes appear to have their basis either in tacitly learned associations (e.g., Osman & Stavy, 2006; Sloman, 1996) or in rules that have been deliberatively acquired but practiced to a state of automaticity (e.g., Kahneman & Klein, 2009). Research has also indicated that prior activation of specific knowledge structures can prime successful problem-solving through implicit mechanisms. For example, Kokinov (1990; Kokinov & Petrov, 2001) showed that priming can facilitate performance with complex deductive, inductive, and analogical reasoning problems, benefitting both the strategy taken and the success/failure ratio. Schunn and Dunbar (1996) corroborated these findings in an analogical problem-solving paradigm, demonstrating that conceptual knowledge of one knowledge domain (biochemistry) can spontaneously influence complex reasoning in another, unrelated knowledge domain (molecular genetics) via implicit priming, leading to facilitated problem-solving as measured through both accuracy and speed of solution generation. Schunn and Dunbar's sophisticated controls and measures also allowed the involvement of explicit memory processes to be ruled out as a cause of solution success in the priming conditions.

Although previous research has confirmed that true memories can effectively prime solutions in problem-solving tasks, the question remains as to whether memory illusions, which are also a product of our reconstructive memory system, can likewise prime solutions in such tasks. That is, because false memories occur with some regularity, we can ask whether they are just a necessary and epiphenomenal evil that arises because of the reconstructive nature of remembering the past and trying to anticipate the future, or can they, like true memories, serve some fitness-relevant function? Using implicitly generated information to solve problems is a key feature in many proposals concerning the nature of creative problem-solving (Hélie & Sun, 2010) and, of course, false memories do come under the rubric of information that is generated automatically, outside of conscious awareness. Indeed, implicit information may have an advantage over explicitly generated information in terms of threat or stress (e.g., Porter & Leach, 2009) or when solving complex problems using "deliberation-without-attention" (Dijksterhuis, Bos, Nordgren, & van Baaren, 2006; Dijksterhuis & Nordgren, 2006).

As a first approximation to answering this question, we examined insight-based, creative problem-solving (Howe, Garner, Charlesworth, & Knott, 2011; Howe, Garner, Dewhurst, & Ball, 2010). Such problem-solving is thought to involve spreading activation processes much like those that mediate the formation of spontaneous false memories in the DRM paradigm (Bowden, Jung-Beeman, Fleck, & Kounios, 2005; Mednick, 1962). Concerning the latter, both the associative-activation theory (AAT, Howe et al., 2009) and the activation-monitoring theory (AMT, Roediger, Balota, & Watson, 2001) suggest that false memories are formed due to implicit activation of critical lures upon presentation of items on the DRM list. Activation from list members spreads to other lexical items in memory, extending to the unpresented critical lure as well as to other unpresented items. This activation can reverberate among items in memory (presented or not) as well as back from these unpresented items to items that were presented (Anderson & Lebiere, 1998). Similarly, for insight-based problems, spreading activation mechanisms can be triggered when problem solvers encounter a concept (e.g., an item within an insight-based problem) and this activation assists problem-solving inasmuch as it provides a preliminary search through the memory network for related concepts. This search spreads to both related and unrelated concepts and continues until those concepts that are crucial to the problem solution become active and an insightful solution is achieved (Bowden et al., 2005; Kershaw & Ohlsson, 2004).

Howe et al. (2010) were the first to carry out research investigating the role that false memories play in priming insight-based solutions using compound remote associates tasks (CRATs) (see Mednick, 1962; Sio, Monaghan, & Ormerod, 2013). CRAT problems, originally developed by Mednick (1962), involve the presentation of three words (e.g., *apple*, *family*, and *house*), which can be associated by a common solution word (e.g., *TREE*). Howe, Garner, Dewhurst, et al. (2010) presented adults with DRM lists whose critical lures served as potential primes for half of the subsequent CRAT problems that participants had to solve. They found that when participants falsely recalled the critical lures of the studied DRM lists, the corresponding CRATs were solved more frequently and significantly faster than CRATs that had not been primed by DRM lists or CRATs that were primed but the critical lure had not been falsely recalled.

Howe et al. (2011) extended this research to children. They recruited both child (11-year-olds) and adult participants (18-year-olds) and, using age-normed CRATs, found that regardless of age, CRATs were solved at a significantly higher rate and more quickly when the critical lures of the studied DRM lists had been falsely recalled compared with instances when the critical lures were not falsely recalled and instances when the CRATs had not been primed by prior DRM lists. This research shows that like true memories, false memories can successfully prime higher order cognitive tasks (i.e., insight-based problem-solving). Moreover, this research challenges the view that false memory illusions are inherently maladaptive and, like false beliefs (McKay & Dennett, 2009), highlights the positive contributions of false memory illusions, namely the assistance they offer during complex problem-solving.

Because of the robust nature of this effect, it requires an adequate explanation that includes a clear depiction of the mechanisms that mediate memory-based priming effects in creative problem-solving. First, these findings are important in terms of theories of spontaneous false memory formation. Indeed, they are consistent with the false memory theories mentioned earlier that invoke spreading activation mechanisms (e.g., AAT, Howe et al., 2009). This is because false memories that have been activated during DRM list presentation are still above threshold in memory when participants are trying to solve CRAT problems. That is, solving CRATs becomes easier because spread of activation from the CRAT terms to the critical lure (or problem solution) is faster given that the critical lure is already active in memory. Indeed, problem-solving is *dependent* on false memory activation levels because solution times are faster and solution rates higher when participants falsely remember the critical lure than when they do not. Other models of false memory that do not involve spreading activation mechanisms may have more difficulty accounting for these findings. For example, fuzzy-trace theory (e.g., Brainerd & Reyna, 1993) suggests that false memories rely on the extraction of gist (or meaning) traces and not on the spread of activation within memory. Given the absence of contradictory information (e.g., verbatim traces), items that are consistent with the extracted gist may be falsely remembered along with actually presented information during recall or recognition tests. It is clear that fuzzy-trace theory can account for the fact that the term *SWEET* may be falsely remembered when the DRM list *sour, sugar, bitter, … cake, tart* has been presented as it is consistent with the gist (e.g., "things that are sweet"). However, it is less clear that this gist is consistent with the solution to the corresponding CRAT problem involving the terms *heart*, *shop*, and *tooth*. Indeed, gist having to do with "love" may be more appropriate to the solution *SWEETheart*. In fact, in some cases, the gist extracted from DRM lists may be more of a hindrance (e.g., interfere with) than of assistance when it comes to solving some of the CRAT problems.[1]

Second, Howe et al. (2010, 2011) argued that this priming effect occurred during the encoding of the DRM lists (i.e., at study) and not during retrieval (i.e., on the recall test). This assumption is generally consistent with the DRM literature that shows that critical lures tend to be generated at encoding and not during retrieval (e.g., Dewhurst, Bould, Knott, & Thorley, 2009; Dewhurst, Knott, & Howe, 2011). However, there is a problem with this latter conclusion. Specifically, Howe et al. (2010, 2011) had shown that priming of problem solutions only occurred when participants had falsely recalled the critical lures during the memory test. What this means is that to determine whether participants had falsely remembered the critical lure, a memory test was necessary. Of course, once a memory test is administered, it is difficult to say unambiguously that priming occurred during study because it is equally plausible that it occurred during the test itself.

To solve this problem, Howe et al. (2010, 2011) conducted a second experiment in which no memory test was administered. That is, participants simply studied the DRM lists and then solved CRAT problems, effectively eliminating the testing confound. Given that they used the same DRM lists and CRATs in this second experiment as in the first, if priming occurred during encoding then similar percentages of false memories would be anticipated in this second experiment, despite the absence of the memory test, and thus similar advantages should have been observed in CRAT solution rates and times. This is exactly what they found. That is, CRATs that had been primed with DRM lists were solved more frequently and more rapidly (at rates and times commensurate with those observed in their first experiments) than CRATs that had not been primed. It would seem, then, that false memory priming of CRATs occurs at encoding and not during retrieval tests.

Given that these robust findings are not just novel but also have important theoretical implications, particularly in terms of understanding the locus of false memory effects and how they serve as primes for subsequent problem-solving, it is imperative that they generalise to other indices of remembering (i.e., recognition as well as recall) and are not subject to alternative interpretations. Unfortunately, Howe et al.'s (2010, 2011) design and measurement changes may not provide an optimal solution to determining the locus of false memory priming effects in problem-solving. Although the testing confound was eliminated, Howe and colleagues were no longer able to measure false memory strength, hence the effectiveness of the prime, using a memory test. That is, because the priming of problem-solving requires the false recollection of the critical lure, some sort of memory test is needed to confirm whether false recollection has occurred for specific primes. More importantly, eliminating the memory test does not enable an assessment of test-induced priming effects or for the magnitude of these effects to be contrasted with those found at study.

[1] Because it is not clear that such models can account for reasoning-remembering dependencies observed in the false-memory, problem-solving literatures being considered here, or at least not as easily as theories based on spreading activation mechanisms, they will not be considered further in this article.

Because it is important to provide a clear and convincing demonstration that false memories can and do have positive consequences on human cognition, in the current article, we resolve the problems associated with previous research so that the demonstration and meaning of these positive effects is not compromised by competing interpretations. We do this by switching to a recognition measure rather than a recall measure. Thus, in the present research, we assigned participants to one of three conditions: one in which priming, thus activation of the critical lure, can occur during both study and test (the "Study and Test" condition in which relevant DRM lists are studied and a recognition test that includes the critical lures is used to gather data during the test phase); one in which priming, thus activation of the critical lure, can only occur during the study phase (the "Study Only" condition in which relevant DRM lists are studied but there is no recognition test); and one in which priming, thus activation of the critical lure, can only occur during memory testing (the "Test Only" condition in which CRAT-irrelevant DRM lists are studied but the recognition test includes the CRAT-relevant critical lures).

This design has three advantages. First, it overcomes the memory test confound, given that the "Study Only" condition does not include a memory test. Second, it permits the conditionalising of CRAT solutions into those solved with and without false recollection of the critical lure using the "Study and Test" condition. Third, the "Test Only" condition provides a new condition in which we can estimate the impact of seeing the critical lure only at test. Consequently, this design permits an evaluation of whether the activation of the critical lure during encoding ("Study Only"), during retrieval ("Test Only"), or both ("Study and Test") is important to priming CRAT solutions.

We predicted that when false memories do occur, the primed CRAT problems should be solved more often and more rapidly than the unprimed CRAT problems and than primed problems where no false recollection occurred. Furthermore, if activation of the critical lure at *study* (i.e., encoding) is the key to enhancing CRAT performance, then it is expected that the solution times and rates will be approximately equal across the "Study and Test" and "Study Only" conditions, but lower and slower in the "Test Only" condition and for the unprimed CRATs. Alternatively, if the presence of the critical lure at *test* (i.e., retrieval) contributes to enhancing CRAT performance (where this effect is predicted to be smaller than the effect of priming at study), then solution times and rates are expected to be faster and greater in the "Study and Test" condition compared with the "Study Only" condition, which in turn will have faster and greater solution times and rates compared with the "Test Only" condition, which in turn will have faster and greater solution times and rates compared with the unprimed CRATs.

To examine these hypotheses, we conducted two experiments. In the first experiment, we used a subset of some newly created and normed CRAT problems (see Appendix A), along with their corresponding DRM lists, to provide a "proof of concept" for false memory priming effects using the newly devised recognition paradigm with adult participants. In Experiment 2, we examined the comparability of these findings to those of previous research that had used recall rather than recognition as a measure of false memory by using identical CRAT-DRM pairings to Howe et al. (2011). We were also interested in whether our recognition paradigm, like the recall one used previously, produced similar effects in children and adults. Therefore, we tested children (11-year-olds) and adults (20-year-olds) using the same age-appropriate CRATs deployed in earlier studies involving recall as the measure of false memories (Howe et al., 2011). As in this previous research, although adults may exhibit more false memories than children, our central concern was whether children's and adults' priming effects are similar given problem-solving tasks equated for relative difficulty. That is, we used age-appropriate CRAT problems because we were interested in whether we could attenuate (or eliminate) age differences in problem-solving rates by using age-appropriate problems. Thus, age differences in problem difficulty were not, in and of themselves, of interest in this study. Rather, we wondered whether false memories could serve the same priming function for children as they do for adults when problem difficulty was equated across age and whether the locus of these priming effects were developmentally invariant.

Experiment 1

Method

Participants

A total of 48 university students participated in this experiment.

Design, materials, and procedure

Participants were randomly assigned to one of the three between-participants' conditions: "Study and Test", where participants studied DRM lists, were given a 30 sec distractor task (letter search), followed by a recognition test, and finally solved CRAT problems; "Study Only", where participants studied DRM lists, were given a filler task, and then solved CRAT problems; and "Test Only", where participants studied CRAT-irrelevant DRM lists, were given a 30 sec distractor task (letter search), followed by a recognition test containing CRAT-relevant but unstudied critical lures, and then solved CRAT problems. All participants were primed on half the CRATs but not the other half. Both the order of the DRM lists and CRATs were counterbalanced to eliminate order effects.

Ten CRATs (ARMY, BLACK, FLAG, GIRL, HEALTH, LONG, RUBBER, SMOKE, SPIDER, and WINDOW) were selected from normative data reported in Appendix A and were taken from the medium difficulty range (between 20% and 78% solution rate). Ten corresponding DRM lists were used, each of which consisted of 10 associates of the critical lure. These lists were split into two sets of five, so participants would be primed with half the DRM lists, while completing all 10 of the CRATs. Each set was balanced for solution rate difficulty and the DRM lists were equated for backward associative strength.

Two recognition tests were created with items used on these tests being condition dependent. For the "Study and Test" condition, items consisted of the 5 critical lures from the studied DRM lists, 5 unstudied and unrelated critical lures, 32 true items from the studied DRM lists, 32 foils unrelated to studied DRM lists, and 8 filler items. For the "Test Only" condition, items consisted of 5 critical lures that were not studied but were CRAT solutions, 5 critical lures for the irrelevant DRM lists that were studied but were not CRAT solutions, 32 true items corresponding to the irrelevant DRM lists, 32 foils unrelated to the studied DRM lists and the subsequent CRAT problems, and 8 filler items. No associates to the critical lures that were CRAT solutions were included, to ensure that no false memories for these items were created at test. No recognition test was needed for the "Study Only" condition. Instead, a filler task (a letter search task) was used that took the same time to complete as the distractor and recognition tasks in the other conditions.

In the "Study and Test" and "Study Only" conditions, participants were given 5 out of the 10 DRM lists in a randomised order on a computer screen. Participants in the "Test Only" condition were given five irrelevant DRM lists to study. This was followed by a distractor task (letter search) and the appropriate recognition test, to which the participants gave their response verbally. Participants were then asked to complete all 10 CRATs. Participants were first given an example, followed by two practice CRATs, before the test CRATs were presented. Each CRAT was presented on a computer screen, in a randomised order, and participants were asked to provide a solution verbally. If participants failed to correctly solve a CRAT, they were given feedback as to the correct answer after each problem. Solutions were timed and participants were given a maximum of one minute to complete each problem.

Results and discussion

Both the mean CRAT solution rates (proportion correctly solved) and the mean CRAT solution times (seconds) were analyzed using separate 2 (Priming: primed vs. unprimed) × 3(Condition: study and test vs. study only vs. test only) analyses of variance (ANOVA). For solution rates, there was a main effect of priming, $F(1, 45) = 12.00$, $p < .01$, $\eta_p^2 = .21$, where the mean CRAT solution rate was higher when participants were primed ($M = .64$, SE = .03) than when they were not primed ($M = .52$, SE = .03). There was no significant main effect of condition [$F(1, 45) = 2.53$, $p = .09$, $\eta_p^2 = .10$] but there was a significant Priming × Condition interaction, $F(2, 45) = 5.09$, $p = .01$, $\eta_p^2 = .18$ (see Figure 1). A simple main effects analysis with Bonferroni-adjusted pairwise comparisons showed that there were no differences across conditions for unprimed CRATs [$M = .45$ (SE = .06), $M = .60$ (SE = .05), and $M = .54$ (SE = .05) for the "Study and Test", "Study Only", and "Test Only" conditions, respectively) but for primed CRATs the "Study and Test" ($M = .66$, SE = .05) and "Study Only" conditions ($M = .74$, SE = .05), which did not differ, were superior to the "Test Only" Condition ($M = .51$, SE = .05), $F(2, 45) = 4.94$, $p = .01$, $\eta_p^2 = .18$. For solution times, the ANOVA revealed a main effect of priming, $F(1, 45) = 16.37$, $p < .01$, $\eta_p^2 = .27$, where the mean CRAT solution times were lower when participants were primed ($M = 31.01$ sec, SE = 1.75) than when they were not primed ($M = 37.01$ sec, SE = 1.66). There was no significant main effect of condition [$F(2, 45) = 1.95$, $p = .15$, $\eta_p^2 = .08$] and no Priming × Condition interaction [$F(2, 45) = 1.26$, $p = .29$, $\eta_p^2 = .05$].

Although average false memory rates were 70%, there were a number of cases in which participants did not

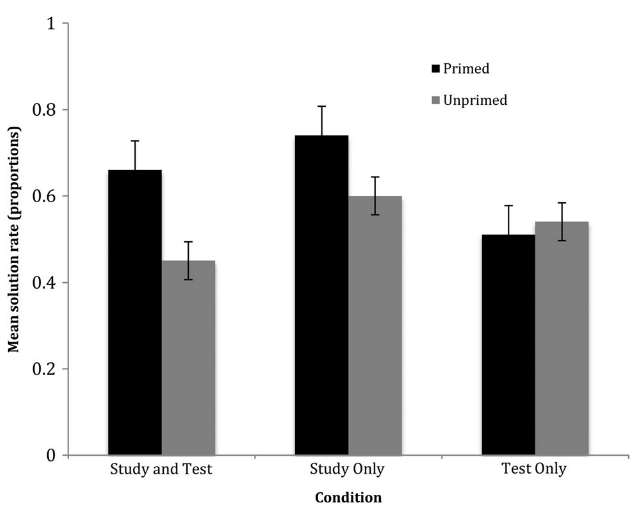

Figure 1. Mean CRAT solution rates (proportions) as a function of priming (primed vs. unprimed) and condition (Study and Test vs. Study Only vs. Test Only), with 95% confidence interval error bars for Experiment 1.

falsely recognise the critical lure when primed. To examine whether priming in the "Study and Test" condition was contingent on false recognition of the critical lures, solution rates and times were conditionalised on whether the participant had falsely recognised the critical lure during testing. More specifically, the primed CRAT problem responses were separated into those solved with a false memory and those solved without a false memory. Those with false memories were then compared to those without false memories using paired *t*-tests. For solution rates, the *t*-test was significant, $t(15) = 2.36$, $p < .05$, where participants who were primed and had a false memory solved more CRATs ($M = .66$, SD = .32, MSE = .08) than those who were primed and had no false memory ($M = .39$, SD = .42, MSE = .10). Importantly, this latter solution rate did not differ from unprimed CRAT solution rates. For solution times, the *t*-test revealed that participants who were primed and had a false memory solved CRATs more quickly ($M = 31.45$ sec, SD = 14.65, MSE = 3.66) than those who were primed and had no false memory ($M = 43.08$ sec, SD = 21.25, MSE = 5.31), although this difference only approached significance ($t(15) = -2.02$, $p = .06$). Like solution rates, solution times for those who were primed but did not falsely recognise the critical lure did not differ from unprimed CRAT solution times.

Together, these results are the first to show that the effects of false memory priming on problem-solving performance are greatest when the critical lure primes are induced during the study phase as opposed to being presented at test. That is, solution rates and solution times were better when priming occurred in the "Study and Test" or "Study Only" conditions relative to the "Test Only" condition. Consistent with the general literature on the locus of false memories, critical lures become active during the encoding process and can serve to prime performance on other tasks ["superadditive priming" (Hancock, Hicks, & Marsh, 2003)]. In our case, this other task involves higher cognitive processes, namely, problem-solving. Moreover, these effects are strongest for participants whose false memory activation is sufficiently strong to produce false recognition of the critical lure during testing. Critically, however, the priming advantage was no greater in the "Study and Test" condition than in the "Study Only" condition, a finding that indicates that the addition of a recognition test did not contribute to the overall priming effect. Before theoretical implications of these findings are considered, we examine whether these findings hold across different CRAT problems and generalise across age.

Experiment 2

Having established false memory priming effects for adults' creative problem-solving in this new recognition memory paradigm, we can now turn to an experiment in which we test the generalisability of these findings. Specifically, we examine whether these effects extend to children by using the same CRAT-DRM pairings that were used successfully in a similar priming experiment (but one that used recall, not recognition, as a measure of false memory) with children and adults (Howe et al., 2011).

Method

Participants

Thirty-six children ($M = 10.9$ years, SD = .4 years; 21 females) and 36 adults ($M = 20.3$ years, SD = 2.3 years; 20 females) participated in the experiment. All were fluent in English. Child participants were recruited from a predominantly White, middle-class school. Prior to the experiment, written informed consent was obtained from the adult participants and written informed parental consent was obtained for all child participants. In addition, the assent of each participant was provided on the day of testing.

Design, materials, and procedure

A 2(Age: 11-year-olds vs. 20-year-olds) × 3(Condition: study and test vs. study only vs. test only) × 2(Priming: primed vs. unprimed) design was used, where the first two factors were between-participants and the latter factor was within participant. For the 11-year-old participants, eight CRATs were chosen from the child normative data produced by Howe et al. (2011; see Appendix B in the current article). For the adult participants, eight CRATs were selected from the normative data in Appendix A and from the Bowden and Jung-Beeman (2003; see Appendix C in the current article) norms. In addition, 16 DRM lists were selected for use in the "Study and Test" and "Study Only" conditions: 8 for use with the 11-year-old participants and 8 for use with the adult participants (see Appendixes B and C, respectively). DRM lists were selected from Stadler, Roediger, and McDermott (1999) as well as from the Nelson, McEvoy, and Schreiber (2004) norms. Each of the 16 DRM lists contained the top 10 items in backward associative strength and was presented in descending order of associative strength to the critical lure. The eight DRM lists studied by the 11-year-old participants and the eight DRM lists studied by the adult participants were randomly divided into two sets of four and counterbalanced across participants, so that all CRATs were primed an equal number of times within each age group.

An additional eight DRM lists were selected for use in the "Test Only" condition (see Appendixes B and C). These eight lists were unrelated to the 16 DRM lists used in the "Study and Test" and "Study Only" conditions, as well as the 16 CRATs. The eight unrelated DRM lists were chosen from Stadler et al. (1999) and the same lists were used for both 11-year-old participants and adults (lists were selected that were suitable for both the children and adults).

In addition to the selected CRATs and the DRM lists, a series of eight recognition tests were constructed. Four of these recognition tests were used in the "Study and Test" condition, two of which were specific to the child participants and two of which were specific to the adult participants. The other four recognition tests were constructed for use in the "Test Only" condition. Each recognition test consisted of 56 items: the 4 unpresented critical lure primes; 6 presented items from each of the 4 DRM lists studied, 3 of which were high associates of the critical lure and 3 of which were low associates of the critical lure; 4 unpresented but related items, 1 for each of the 4 DRM lists studied (these were typically the 14th or the 15th item from the original DRM lists and we included these items as a measure of false memories for weak associates: see Nelson et al., 2004; Stadler et al., 1999); and 24 filler items, which were 3 items chosen at random from 8 completely unrelated DRM lists, randomly selected from Roediger, Watson, McDermott, and Gallo (2001).

All participants were tested individually in a quiet, unoccupied room. As in Experiment 1, the procedure differed depending upon the condition that the participant had been assigned to. Participants randomly assigned to the "Study and Test" condition received general memory instructions that informed them that they would be verbally presented with four lists, one after the other, and that they should listen carefully to each list. Participants were subsequently presented with one set of four DRM lists in a randomised order. A distractor task (a letter search task) was then administered for a period of 30 sec. Following the distractor task was a 56-item recognition test. Finally, participants completed a set of eight CRAT problems. Participants were first provided with an example CRAT followed by a practice CRAT, which they had to solve correctly in order to advance on to the eight test CRATs. The example CRAT, the practice CRAT, and each of the eight test CRATs were presented on a computer screen as well as being read aloud by the experimenter. Participants provided a verbal response to the CRATs. Participants had a maximum of 60 sec to complete the practice CRAT and had a maximum of 60 sec per each of the eight test CRATs. Any test CRAT that was not solved within the 60 sec was classified as being *unsolved* and participants were given feedback on the correct answer before advancing on to the next test CRAT. The order of presentation of the CRATs was randomised for each participant. Solution times were measured from the presentation of the word problem to the time at which the correct solution was given.

Participants randomly assigned to the "Study Only" condition were also given general memory instructions to begin; participants were informed that they would be read aloud four word lists, one after the other, and that they should listen carefully to each word list that was to be presented. Participants were then presented with one set of four DRM lists in a randomised order followed by a distractor task for a period of 210 sec, a time that equalled the average amount of time taken to present the 56-item recognition test and carry out the distractor task for a period of 30 sec, in the "Study and Test" and "Test Only" conditions. This was done to ensure that the delay interval between list presentation and CRAT testing was constant across all between-participant conditions. The CRATs followed the distractor task; the same procedure was used here as in the "Study and Test" condition.

In the final "Test Only" condition, the testing procedure was equivalent to that in the "Study and Test" condition with the sole exception of the stimuli that were presented to the participants; the DRM lists in the "Test Only" condition were completely unrelated (thus irrelevant) to the later CRATs.

Results and discussion

In line with Experiment 1, both the mean CRAT solution rates (proportion correctly solved) and the mean CRAT solution times (seconds) were analyzed using separate 2(Age: 11- vs. 20-year-olds) × 3(Condition: study and test vs. study only vs. test only) × 2(Priming: primed vs. unprimed) ANOVAs.

Solution rates

There was a significant main effect of priming, $F(1, 66) = 87.62$, $p < .001$, $\eta_p^2 = .57$, where solution rates were higher for primed CRATs ($M = .82$, SE = .02) than unprimed CRATs ($M = .56$, SE = .03). There was also a significant main effect of condition, $F(2, 66) = 8.09$, $p = .001$, $\eta_p^2 = .20$, where *post hoc* tests revealed that solution rates were higher in the "Study and Test" ($M = .79$, SE = .04) and the "Study Only" ($M = .71$, SE = .04, $p > .05$) conditions, which did not differ, compared with the "Test Only" condition ($M = .57$, SE = .04, $p < .001$ and $p < .05$, respectively). Furthermore, there was a significant main effect of age, $F(1, 66) = 6.42$, $p < .05$, $\eta_p^2 = .09$, where children exhibited higher solution rates for the CRATs than the adults ($M = .75$, SE = .03, and $M = .63$, SE = .03, respectively). This finding was unexpected given that age-normed stimuli were used. However, although the age effect was statistically significant, the difference between the children's and adults' solution rates was small (.12). Furthermore, there is an obvious explanation as to why there was an age effect in the unexpected direction; the CRATs selected for use with the children had an average normed solution rate of 54%, whereas the CRATs selected for use with the adults had a lower average solution rate of 45%. Therefore, the children's CRATs were simply easier to solve to begin with compared to the adults' CRATs.[2]

Additionally, there was a significant Priming × Condition interaction, $F(2, 66) = 6.77$, $p < .01$, $\eta_p^2 = .17$. A simple main effects analysis with Bonferroni-adjusted pairwise comparisons showed that the solution rates for the primed CRAT problems were higher than the solution rates for the unprimed CRAT problems, regardless of the condition.

[2] We identified that one of the child-normed CRATs was performing at ceiling (>.80; see Table 1). This main effect of age was no longer significant ($p > .05$) when we ran analyses that controlled for this ceiling effect.

Table 1. The mean solution rates (%) for the adult- and child-normed CRATs.

Adults		Children	
CRAT	Mean Solution Rate (%)	CRAT	Mean Solution Rate (%)
BREAD	69	APPLE	50
COLD	66	COFFEE	58
FRUIT	60	FOOT	58
GOLD	63	GUN	33
LION	71	PAPER	75
NEEDLE	76	PEN	50
SUN	61	TABLE	49
SWEET	29	TREE	79
WINDOW	83[a]	STREET	57

[a]At ceiling (>80%).

The source of the Priming × Condition interaction was in terms of the *magnitude* of these effects (see Figure 2). The primed and unprimed solution rates in the "Study and Test" condition were .94 (SE = .03) and .64 (SE = .05), respectively, which was a significant difference of .30 ($p < .001$). The primed and unprimed solution rates in the "Study Only" condition were .89 (SE = .03) and .54 (SE = .07), respectively, which was a significant difference of .35 ($p < .001$). The primed and unprimed solution rates in the "Test Only" condition were .63 (SE = .05) and .51 (SE = .05), respectively, which was a significant difference of .12 ($p < .01$). A quantitative difference was therefore evident between the primed CRAT solution rates and the unprimed CRAT solution rates across the three conditions; the difference between the primed and unprimed CRAT solution rates for the "Study and Test" and "Study Only" conditions was quantitatively larger (by a factor of three) than the difference between the primed and unprimed CRAT solution rates in the "Test Only" condition (see Figure 2). That is, both the "Study and Test" and "Study Only" conditions showed a 30–35% gain for primed versus unprimed CRAT solution rates, whereas the "Test Only" condition showed only a modest 12% gain for primed versus unprimed CRAT solution rates. Thus, although minor improvements in CRAT solution rates were observed when the CRAT solution words were physically presented to the participants at test (i.e., the solution words were included as part of the recognition test of memory) prior to them completing the eight test CRATs, the gains from having generated the solution words at study, prior to completing the eight test CRATs, were three-fold greater.

Solution times

There was a significant main effect of priming, $F(1, 66) = 70.35$, $p < .001$, $\eta_p^2 = .52$, where solution times were quicker for the primed CRATs ($M = 21.13$ sec, SE = 1.03) compared with the unprimed CRATs ($M = 29.39$ sec, SE = 1.20). In addition, there was a significant main effect of condition, $F(2, 66) = 12.98$, $p < .001$, $\eta_p^2 = .28$, and *post hoc* tests showed that the solution times were quickest in the "Study and Test" condition ($M = 18.96$ sec, SE = 1.74), followed by the "Study Only" condition ($M = 25.37$ sec, SE = 1.74), which both produced quicker solution times compared with the "Test Only" condition ($M = 31.45$ sec, SE = 1.74). There was no main effect of age [$F(1, 66) = .26$, $p = .61$, $\eta_p^2 = .00$], where the average time taken to solve a CRAT was 24.75 sec (SE = 1.42) for children and 25.77 sec (SE = 1.42) for adults.

Additionally, there was a significant Priming × Condition interaction, $F(2, 66) = 6.51$, $p < .01$, $\eta_p^2 = .17$. A simple main effects analysis with Bonferroni-adjusted pairwise comparisons showed that the solution times for the primed CRATs were faster than the solution times for the unprimed CRATs regardless of the condition. Again, the source of the Priming × Condition interaction was in terms of the *magnitude* of these effects (see Figure 3). The primed and unprimed solution times for the "Study and Test" condition were 13.50 sec (SE = 1.21) and 24.42 sec (SE = 2.09), respectively, which was a significant difference of 10.92 sec ($p < .001$). The primed and unprimed solution times

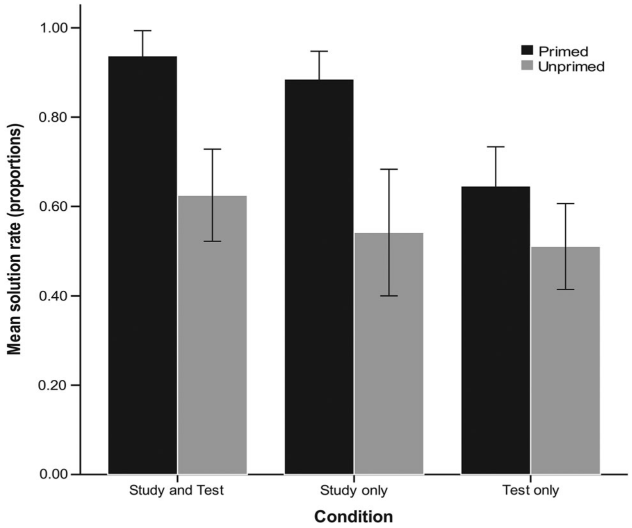

Figure 2. Mean CRAT solution rates (proportions) as a function of priming (primed vs. unprimed) and condition (Study and Test vs. Study Only vs. Test Only), with 95% confidence interval error bars for Experiment 2.

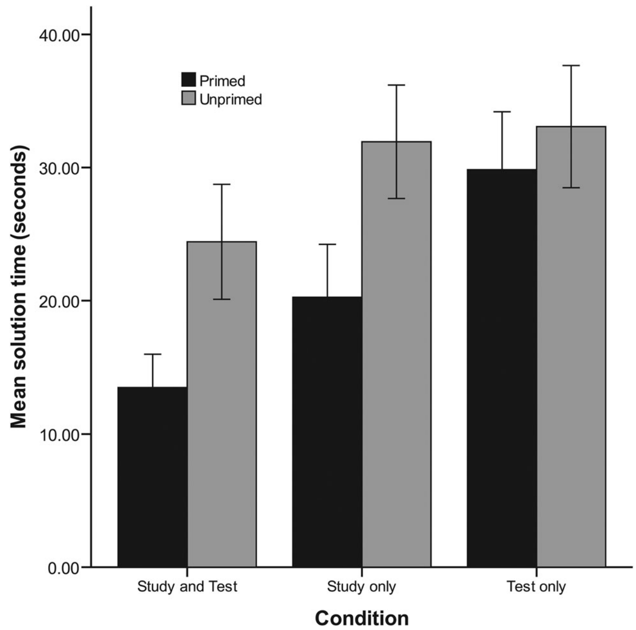

Figure 3. Mean CRAT solution times (seconds) as a function of priming (primed vs. unprimed) and condition (Study and Test vs. Study Only vs. Test Only), with 95% confidence interval error bars for Experiment 2.

for the "Study Only" condition were 20.07 sec (SE = 1.91) and 30.68 sec (SE = 1.80), respectively, which was a significant difference of 10.61 sec ($p < .001$). The primed and unprimed solution times for the "Test Only" condition were 29.84 sec (SE = 2.10) and 33.07 sec (SE = 2.22), respectively, which was a significant difference of 3.23 sec ($p < .05$). A quantitative difference was therefore evident between the primed CRAT solution times and the unprimed CRAT solution times across the three conditions; the difference between the primed and unprimed CRAT solution times in the "Study and Test" and "Study Only" conditions was quantitatively greater (by a factor of three) than the difference between the primed and unprimed CRAT solution times in the "Test Only" condition (see Figure 3). That is, there was a reduction in CRAT solution times of around 11 sec for primed versus unprimed CRATs in both the "Study and Test" and "Study Only" conditions, whereas the reduction was only approximately 3 sec for primed versus unprimed CRATs in the "Test Only" condition. Hence, although there was a slight increment in performance (i.e., faster solution times were produced) when participants were physically presented with the solution words on a recognition memory test prior to them solving the eight test CRATs, the gains from inducing the solution words at study, prior to them completing the eight test CRATs, were also threefold greater.

Given that the false memory rates of the participants in the "Study and Test" condition were recorded, as in Experiment 1, CRAT performance could be further conditionalised by separating the CRATs into (a) primed CRAT problems solved where the false memory was produced (primed/FM), (b) primed CRAT problems solved where the false memory was not produced (primed/No-FM), and (c) the unprimed CRAT problems that were solved. However, because false memory rates in the "Study and Test" condition were close to ceiling for both age groups, as seen in the analyses of the "Study and Test" condition performance earlier, we reanalyzed the data using only nonceiling participants from the "Study and Test" condition.

There were two important outcomes concerning these reanalyses. First, the same pattern of results was obtained when only nonceiling participants were included in the analyses already reported. Second, when we conditionalised CRAT performance on the basis of false recognition rates for the "Study and Test" participants' solution rates, there was a significant main effect for priming, $F(2, 20) = 5.09$, $p < .02$, $\eta_p^2 = .46$. *Post hoc* tests ($p < .05$) showed that those who were primed and falsely recognised the critical lure solved more CRATs ($M = .93$, SD = .08, MSE = .02) than those who were primed and did not falsely recognise the critical lure ($M = .50$, SD = .38, MSE = .07).

General discussion

Clearly, false memories like true memories can have positive consequences when it comes to children's and adults' cognitive processes. The present research provides a convincing demonstration that false memories can serve as effective primes when children and adults are attempting to solve problems, particularly ones that require insight-based solutions. Thus, that false memories are an aspect of a flexible, reconstructive memory system does not necessarily mean that the consequences of memory illusions are negative. Indeed, as shown here, depending on the context in which false memories occur, they can and do exert a very positive influence on human cognition (cf. Howe, 2011; Schacter et al., 2011).

Equally important, the findings that have emerged from the present research allow us to "drill down" into some of the mechanisms that are responsible for these positive effects of false memories. Specifically, these results establish that the effects of priming on problem-solving performance are greatest when the critical lure primes are induced during the study phase as opposed to being presented at test. Across both experiments, these priming effects were robust and their encoding locus consistent with our predictions. Moreover, this research is the first to generalise previous findings where recall measures were used to evaluate memory performance (Howe et al., 2010, 2011) to memory measures involving tests of recognition. Indeed, regardless of the memory measure being used, priming insight-based problem solutions, either through the prior presentation of DRM lists whose critical lures are also the solutions to the subsequent problems, or through the inclusion of critical lure primes on a recognition test of memory, significantly increases solution rates and quickens solution times relative to unprimed problem solution rates and times. This adds to the growing consensus that false memories, like true memories, can successfully prime higher cognitive processes, at least in terms of problems involving insight-based solutions.

Moreover, our research has clearly shown that false memory priming effects are developmentally invariant. We demonstrated this in two ways. First, priming effects were equally robust in both child and adult populations. That is, when age-appropriate materials were used, the magnitudes of these priming effects were similar in children and in adults. Second, the locus of these priming effects did not differ with age with the bulk of these effects occurring at encoding. This developmental invariance is important theoretically. That is, our results demonstrate that despite well-known age differences in true and false memory rates (where children routinely produce fewer true and false memories than adults—see Brainerd et al., 2011; Howe et al., 2009), once a false memory is produced, it can have the same facilitating effect on subsequent problem-solving regardless of age. Thus, the same spreading activation mechanism may drive reasoning-remembering dependencies in children as it does in adults.

At a more fine-grained level, the outcomes of the present research support the predictions that primed CRATs would be solved more frequently and at a faster rate than unprimed CRATs. Furthermore, it was hypothesised that if encoding was the primary site of priming CRAT performance, then the solution times and rates would be reasonably equal across the "Study and Test" and "Study Only" conditions, which in turn would be superior to the solution times and rates generated by participants in the "Test Only" condition and to the solution times and rates generated in response to the unprimed CRATs. The findings from the present research confirmed these predictions. Moreover, the difference between the solution times and rates for primed versus unprimed CRATs was considerably greater for both children and adults in Experiment 2 in the "Study and Test" and "Study Only" conditions compared to the "Test Only" condition. What this means is that the generation of critical lures during DRM list presentation (i.e., at encoding) is more effective at priming subsequent CRAT problems than explicitly presenting participants with the critical lure primes during a recognition test of memory (i.e., at retrieval). Consequently, the findings that have emerged from the present study show that priming at study is the key to facilitating CRAT performance, as opposed to priming at test.

The critical reader might come to the conclusion that the interpretation of the results from Experiments 1 and 2 is not as straightforward as we contend. Such readers might argue that both these experiments suffer from a potential confound. Specifically, perhaps the different conditions used to dissever the locus of priming effects were confounded with differential levels of exposure to potential primes. For example, the "Study and Test" condition might prime CRATs the most simply because participants were exposed to more priming items during the procedure. That is, participants in this condition were exposed to the 10-item DRM list (where each list item could be considered a weak prime) as well as a subset of these items again on the recognition test and the critical lure. In addition, the "Study Only" condition might prime CRATs better than the "Test Only" condition simply due to the fact that participants in the former condition were exposed to the 10 weak primes at encoding (the items on the each CRAT-relevant DRM list) but participants in the latter condition were only exposed to a subset of those items (and the critical lure) during testing. According to this argument, any condition-wise differences in priming could be due to the stage at which priming took place (encoding vs. retrieval), the amount of exposure to items directly and indirectly related to the CRAT solutions, or both.

The problem with this "pure exposure" argument is that it reduces to one about the role of testing. Specifically, because participants in both the "Study and Test" and "Study Only" conditions were exposed to the same 10-item DRM lists during encoding, the only other exposure differences must be localised at test. Whereas participants in the "Study Only" condition received no additional exposure to the CRAT-relevant critical lure or the related DRM list items, participants in the "Study and Test" condition, like those in the "Test Only" condition, were exposed to a subset of those list items on the recognition test as well as the critical lure. What is clear from the data is that mere exposure to these additional items during a recognition test (the "Study and Test" condition) did not enhance priming levels above that of exposure during "Study Only". Although there was some evidence of priming effects in the "Test Only" condition, the effects due to exposure at study swamped any effects observed from exposure at testing. Consistent with these findings is other recent evidence showing that effects of tests (i.e., test-induced priming) are small relative to the effects of study when it comes to false memory generation, for both children (Dewhurst, Howe, Berry, & Knott, 2012) and adults (Dewhurst et al., 2011). Overall, then, it would seem that any potential confound between *locus* of exposure (study vs. test) and *amount* of exposure does not pose a serious problem and is not, therefore, a source of concern when it comes to interpreting the outcomes of these experiments. Indeed, it would seem safe to conclude that like the generation of false memories themselves, the primary locus of false memory priming effects lies at encoding, not retrieval.

More generally, we would argue that these priming effects, like most priming effects, occur relatively automatically outside of conscious awareness. However, it is always possible that participants may have used a more explicit strategy when solving CRATs. That is, despite presenting the memory and reasoning tasks to participants as being unrelated, there is a possibility that some of the participants figured out that the tasks were connected. If participants did become aware of this relationship, such awareness could have influenced how they went about solving the CRATs—that is, they would be more likely to try to remember previously presented items from the study or test sessions to solve them. Of course, this strategy would greatly benefit the "Study and Test" and "Study Only" conditions because those lists had many items related to the critical lure that could enhance the likelihood of the lure itself being remembered. In the "Test Only" condition, participants may also become aware of the fact that the solutions to the CRATs were linked to the items they were tested on but these would be harder to access because there would be fewer related cues. Moreover, an explicit memory search strategy of this nature would both increase accessibility for studied/tested words and critical lures as CRAT solutions while at the same time make it difficult to find the solution for unprimed items because no matter how hard they search memory for the previous study items, the answer is not in episodic memory for the previously studied materials.

Although the use of such a deliberate strategy is perhaps less likely in children than adults, we believe that this explanation cannot account for these effects more generally for at least two reasons. First, care was taken to ensure that participants did not believe that the memory task and CRATs were related. The study title, description, and instructions to participants explicitly stated that the two tasks were separate and not associated, but rather, that researchers were interested in individual differences in performance on different memory and problem-solving tasks. In addition, participants in the "Study Only" condition were told that they would be given a memory test for the studied lists after they had completed the CRATs. This was done in order to avoid demand characteristics in this condition (such demand characteristics were not a concern for participants in the other conditions because they were given a memory test before the CRATs).

Second, all participants were debriefed following the experiment. One of the questions asked was whether they were aware of any link between the memory and problem-solving tasks. A relatively large percentage (90%) said that they were not aware of any link between the two tasks. Interestingly, when the data from the 10% of participants who claimed to be aware of a link between the two tasks was removed from the analyses, we found no significant changes in the results.

Having ruled out a deliberate memory search interpretation of our results, we believe that the more parsimonious interpretation of this set of findings lies in an automatic priming process, one that is linked to models that incorporate a spreading activation mechanism when explaining performance in associative memory and insight-based reasoning tasks. Indeed, our results are consistent with the associative-activation theory of Howe et al. (2009) as well as the activation-monitoring theory presented by Roediger and McDermott (1995). At the core of these models is the assumption that false memory illusions are driven by spreading activation processes that occur during study. That faster solution times and higher solution rates were produced by participants in the "Study and Test" and "Study Only" conditions is predicted because the spread of activation that results from inducing the critical lure primes at study is believed to be far greater than the spread of activation that results from presenting participants with such items at test (Dewhurst et al., 2009, 2011, 2012; Hancock et al., 2003). The notion that encoding processes that appear to be the key to facilitating CRAT performance is also compatible with findings from previous studies that have investigated whether associations at study or at test drive false memory illusions (e.g., Arndt & Reder, 2003; Dewhurst et al., 2009, 2011, 2012; McCabe, Presmanes, Robertson, & Smith, 2004; Roediger, Balota, et al., 2001; Roediger & McDermott, 1995; Roediger, Watson, et al., 2001). The general consensus that emerged from such research was that false memory illusions (e.g., those produced by DRM tasks) were the result of associations activated during study rather than test. Additional research (e.g., Coane & McBride, 2006; Dewhurst et al., 2009; Marsh & Dolan, 2007) has shown that processes that occur at retrieval rarely influence false memories. The current findings add further support to the notion that associations generated during study as opposed to test facilitate false memory illusions.

Although we have focused on effects at encoding it is important to acknowledge that there were some effects at test. Although these were small, presenting participants with the critical lures on a recognition test prior to them completing test CRATs did increase solution rates and decrease solution times. These modest changes in problem-solving performance were anticipated because recognition tests prompt participants to search through their memories in order to ascertain whether the presented items are new or previously encountered items. Because such memory searches lead to activation of the corresponding memory representations of the items on the recognition test (which in the present study included the critical lure primes), such residual activation from test trials is likely to have some priming effect on CRAT solution rates and times. However, as discussed previously, the spread of activation that results from having encountered an item at test is thought to be less powerful than the spread of activation that results from activating an item at study. Hence, an effect at test, although expected, was predicted to be (and was) much weaker compared to the effects seen at study (see Howe et al., 2009).

The outcomes presented in this article have some important implications. First, false memories have to be sufficiently activated in memory that they can be successfully recalled (Howe et al., 2010, 2011) or recognised (Experiments 1–2) in order for priming to be effective. Importantly, the current experiments clearly showed that activation during encoding can and does facilitate immediate performance on other, non-memory tasks. Second, false memories can effectively prime higher cognitive processes, specifically insight-based, creative problem-solving, across age (i.e., in 11-year-old children and adults). That is, false memory primes can increase both the speed and the rate at which problems are solved compared with unprimed problem solutions for both children and adults. This holds not just for false memories, but also for memories activated by the presentation of the prime during encoding. Thus, regardless of age, when developmentally appropriate materials are used, false memories generated from information presented during encoding can and do facilitate performance on other, non-memory cognitive tasks.

Third, given that we used recognition measures to assess false recollection, whereas previous research in this domain used recall measures, the present study extends priming effect findings to tests of recognition. Thus, developmentally invariant priming effects are observed across the two principal procedures used to measure memory. Fourth, this research is the first to establish that priming during the study, but not the test, phase is key to facilitating CRAT performance. This finding compliments the existing false memory priming effects literature that has routinely shown that false memory illusions are predominantly driven by spreading activation processes that occur during study (i.e., encoding—see, Dewhurst et al., 2009, 2011, 2012; Howe et al., 2009).

Fifth, both the current findings and those from previous studies (Howe et al., 2010, 2011) have extended the range of false memory priming effects by demonstrating that false memories can prime complex, higher order tasks and not simply other, related implicit and explicit memory tasks. Such results have considerable relevance to contemporary debates regarding the links between remembering and reasoning and the possibility of developing a unified model of memory and reasoning processes. One salient debate concerns the status of implicit processes such as intuition in reasoning and problem-solving. Some theorists (e.g., Evans, 2010) suggest that intuition may often be a "false friend", providing rapid, low-effort, default responses that are in fact erroneous. This negative view can be contrasted with a more positive position, whereby implicit forms of processing involving mechanisms such as priming can give rise to intuitions that promote successful reasoning and judgment (e.g., Gigerenzer, 2007; Kahneman & Klein, 2009). This latter position concurs with the proposal that decisions in the face of complex problems are better left to the cognitive unconscious—the so-called "deliberation-without-attention" hypotheses (e.g., Dijksterhuis et al., 2006; Dijksterhuis & Nordgren, 2006). This hypothesis is not without controversy (e.g., see Acker, 2008; Aczel, Lukacs, Komlos, & Aitken, 2011; Ambady, 2010; Lassiter, Lindberg, González-Vallejo, Bellezza, & Phillips, 2009), with some reporting that conscious thought may still be better than unconscious processes (e.g., Huizenga, Wetzels, van Ravenzwaaij, & Wagenmakers, 2012) and that there may be some issues concerning key arguments surrounding the roles of explicit versus implicit memory in producing advantages from supposedly intuitive processing. Regardless, we believe that our findings regarding false memory priming of problem-solving usefully inform this controversy, revealing the beneficial effects of implicitly derived false memories for effective reasoning with complex insight tasks and extending previous research that has revealed beneficial priming of problem-solving via true memories (e.g., Kokinov, 1990; Schunn & Dunbar, 1996).

In conclusion, the present research has focused on the positive consequences of false memory illusions. It is clear that false memories like false beliefs (e.g., McKay & Dennett, 2009) can and do exert beneficial effects upon human cognition, not only in terms of related memory tasks but also when it comes to complex problem-solving (Howe et al., 2010, 2011; McDermott, 1997; McKone & Murphy, 2000). Moreover, and perhaps of greater consequence, priming during encoding facilitates subsequent problem-solving performance more so than when priming occurs only at test. That these effects are developmentally invariant when age-appropriate materials are used is also important because it indicates that for both children and adults, when concepts are present in a participant's knowledge base, spreading activation mechanisms support the formation of spontaneous false memories as well as the more creative process of solving insight-based problems. Hence, memory illusions, like memory accuracies, can and do have fitness-relevant adaptive consequences regardless of age.

Disclosure statement

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Appendix A

In this Appendix, we report a normative study in which we created a new set of CRAT problems specifically for adults. We did this so we could better control CRAT difficulty and use a wider variety of DRM lists than those already available in previously normed CRATs (Bowden & Jung-Beeman, 2003).

A total of 40 university students participated in this normative experiment. Participants were presented with 32 CRATs (see Table A1). The items on the CRATs all required a solution that was a word associated with all three words of the triad through the construction of a compound word or common phrase (e.g., *glasses*, *flower*, and *burn*, are associated by the common, solution word *SUN*: *SUNglasses*, *SUNflower*, and *SUNburn*). Twenty-nine of the CRATs were newly created such that their solutions were also critical lures found in the Roediger, Watson et al. (2001) DRM lists. The three additional problems whose solutions were also critical lures on DRM lists were taken from the original Bowden and Jung-Beeman (2003) norms.

Participants were tested individually in a quiet room. Instructions similar to Bowden and Jung-Beeman (2003) were given. That is, participants were told that they would see three items on a computer screen and that they should try and produce a fourth word, which, when combined with each of the three items, would make up a common compound word or phrase. Participants were first given three demonstrations by the experimenter followed by two practice problems prior to the experiment itself. The three problem words were presented on a computer laptop screen simultaneously in a vertical orientation, one above, below, and at the centre point. The participants were given 60 sec (the longest time limit used by Bowden and Jung-Beeman was 30 sec) to produce the solution. If the solution was produced within the time limit, both the solution and the solution time were recorded and the next problem was presented. If the participant did not produce the correct response within the time limit, the solution was provided by the experimenter and the program automatically moved on to the next problem.

We present the results for both solution rates and solution times in Table A1.

Table A1. New CRAT norms for adults.

CRAT problem	Solution/critical lure	% Solved	Solution time
Crust/stale/french	Bread	93	10.81 (14.86)
Chase/police/toy	Car	90	16.48 (19.23)
Old/hole/super	Man	88	24.48 (19.14)
Note/jazz/sheet	Music	88	15.21 (18.70)
Post/lava/bulb	Lamp	85	18.67 (21.25)
Knitting/pine/work	Needle	85	18.23 (21.29)
Salad/bowl/juice	Fruit	83	22.83 (20.52)
Haul/jump/bow	Long	78	26.49 (23.99)
Band/ball/tyre	Rubber	73	26.61 (24.20)
Spa/mental/care	Health	68	28.84 (24.46)
Shop/washer/frame	Window	60	31.49 (24.82)
Board/mail/magic	Black	58	33.71 (25.41)
Base/territorial/boot	Army	55	37.64 (23.68)
Pole/national/ship	Flag	55	32.32 (25.73)
Flower/friend/scout	Girl	55	38.56 (21.37)
Leg/wheel/high	Chair	53	35.05 (24.89)
Knife/tip/pal	Pen	50	38.10 (24.00)
Drinking/tea/cake	Cup	48	39.39 (23.43)
Football/flannel/vest	Shirt	48	41.27 (22.97)
School/chair/horse	High	43	40.59 (25.23)
Bank/boat/winding	River	40	40.96 (23.92)
Cleaner/magic/woven	Carpet	33	48.89 (18.73)
Skin/tissue/ball	Soft	33	46.80 (20.39)
Stop/wolf/dog	Whistle	30	47.34 (21.33)
Bomb/white/alarm	Smoke	25	50.42 (18.08)
Tooth/potato/heart	Sweet	25	48.75 (20.42)
List/bone/last	Wish	25	47.35 (22.76)
Hold/stool/print	Foot	23	50.63 (19.78)
Limits/sights/break	City	20	51.42 (18.13)
Walk/over/deep	Sleep	18	52.87 (17.20)
Monkey/bite/legs	Spider	18	53.20 (16.90)
Cheese/pie/ivy	Cottage	15	53.12 (17.70)

Note: Standard deviations are in parentheses.

Appendix B

The stimuli selected for use with the 11-year-old participants in Experiment 2: the eight DRM lists chosen from Stadler et al. (1999) and from the normed associates lists created by Nelson et al. (2004), for use in the "Study and Test" and "Study Only" conditions (the critical lure has been underlined); the eight corresponding CRAT problems selected from the child normative data produced by Howe et al. (2011) for use in all three test conditions (the solution word has been underlined and is synonymous to the critical lure of the corresponding DRM list); the eight unrelated DRM lists chosen from Stadler et al. (1999) for use in the "Test Only" condition.

Bread
DRM list: butter, sandwich, jam, milk, flour, jelly, dough, crust, loaf, toast.
CRAT problem: crumb, knife, stale.

Cold
DRM list: hot, snow, warm, winter, ice, wet, chilly, weather, freeze, shiver.
CRAT problem: water, sore, temperature.

Fruit
DRM list: vegetable, citrus, basket, strawberry, kiwi, plum, grape, cherry, lemon, peach.
CRAT problem: juice, salad, bowl.

Gold
DRM list: silver, jewellery, bronze, bracelet, necklace, medal, treasure, brass, metal, shiny.
CRAT problem: fish, mine, ring.

Lion
DRM list: tiger, roar, fierce, mane, jungle, zoo, hunt, Africa, feline, cat.
CRAT problem: cub, sea, king.

Needle
DRM list: thread, pin, syringe, sharp, point, thimble, thorn, hurt, injection, cloth.
CRAT problem: sewing, pine, knitting.

Sweet
DRM list: sour, sugar, bitter, nice, taste, soda, honey, chocolate, cake, tart.
CRAT problem: heart, shop, tooth.

Window
DRM list: door, glass, pane, curtains, house, sill, open, shutter, view, clear.
CRAT problem: frame, cleaner, ledge.

Black
DRM list: white, dark, cat, charred, night, colour, blue, ink, coal, gray.

Car
DRM list: truck, bus, train, vehicle, drive, jeep, race, keys, garage, van.

Doctor
DRM list: nurse, sick, medicine, health, hospital, ill, office, stethoscope, surgeon, clinic.

Music
DRM list: note, sound, piano, sing, radio, band, melody, concert, instrument, orchestra.

River
DRM list: water, stream, lake, boat, tide, swim, flow, barge, creek, brook.

Sleep
DRM list: bed, rest, awake, tired, dream, snooze, blanket, snore, nap, yawn.

Smell
DRM list: nose, breathe, sniff, aroma, hear, see, nostril, scent, fragrance, perfume.

Spider
DRM list: web, insect, bug, fright, fly, crawl, tarantula, poison, bite, creepy.

Appendix C

The stimuli selected for use with the adult participants in Experiment 2: the eight DRM lists chosen from Stadler et al. (1999) and from the normed associates lists created by Nelson et al. (2004), for use in the "Study and Test" and "Study Only" conditions (the critical lure has been underlined); the eight corresponding CRAT problems selected from Bowden and Jung-Beeman (2003) for use in all three test conditions (the solution word has been underlined and is synonymous to the critical lure of the corresponding DRM list); the eight unrelated DRM lists chosen from Stadler et al. (1999) for use in the "Test Only" condition.

Apple
DRM list: core, orchard, pear, pie, fruit, banana, rotten, Newton, cobbler, orange.
CRAT problem: pine, crab, sauce.

Coffee
DRM list: caffeine, tea, café, drip, cup, grind, mug, cream, doughnut, instant.
CRAT problem: break, bean, cake.

Foot
DRM list: walk, hand, toe, kick, sandals, yard, ankle, boot, inch, sock.
CRAT problem: hold, print, stool.

Gun
DRM list: pistol, trigger, weapon, bullet, rifle, shoot, shooting, shot, bang, hunting.
CRAT problem: fight, control, machine.

Paper
DRM list: newsstand, sheet, document, pad, folder, margin, thesis, tissue, staple, notebook.
CRAT problem: fly, clip, wall.

Pen
DRM list: pencil, write, fountain, quill, felt, Bic, scribble, cross, tip, marker.
CRAT problem: knife, light, pal.

Street
DRM list: avenue, boulevard, road, sidewalk, alley, curb, lane, crossing, corner, pavement.
CRAT problem: main, sweeper, light.

Tree
DRM list: oak, sap, stump, leaf, bush, forest, elm, branch, leaves, moss.
CRAT problem: palm, shoe, house.

Black
DRM list: white, dark, cat, charred, night, colour, blue, ink, coal, gray.

Car
DRM list: truck, bus, train, vehicle, drive, jeep, race, keys, garage, van.

Doctor
DRM list: nurse, sick, medicine, health, hospital, ill, office, stethoscope, surgeon, clinic.

Music
DRM list: note, sound, piano, sing, radio, band, melody, concert, instrument, orchestra.

River
DRM list: water, stream, lake, boat, tide, swim, flow, barge, creek, brook.

Sleep
DRM list: bed, rest, awake, tired, dream, snooze, blanket, snore, nap, yawn.

Smell
DRM list: nose, breathe, sniff, aroma, hear, see, nostril, scent, fragrance, perfume.

Spider
DRM list: web, insect, bug, fright, fly, crawl, tarantula, poison, bite, creepy.