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Constructive episodic retrieval processes underlying memory distortion contribute to creative thinking and everyday problem solving

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Abstract
Constructive episodic retrieval processes play an adaptive role in supporting divergent thinking (i.e., creatively combining diverse bits of information) and means-end problem solving (i.e., generating steps to solve a social problem). However, the constructive nature of episodic memory that supports these adaptive functions also leads to memory error. In three experiments we aimed to identify a direct link between divergent thinking and means-end problem solving – as assessed in the Alternative Uses Task (AUT) and Means-End Problem Solving (MEPS) task – with the generation of false memories in the Deese-Roediger-McDermott paradigm. In Experiment 1, we replicated prior findings where false memory was positively correlated with performance on the AUT, and also showed for the first time that increased performance in the MEPS task is associated with increased false recall. In Experiment 2, we demonstrated that the link between false recall and performance on the MEPS task did not extend to other forms of problem solving, as assessed with the Everyday Descriptions Task (EDT). In Experiment 3, we showed that when the EDT was preceded by the MEPS task in an attempt to influence participants to engage in a similar episodic-problem solving strategy, performance in both tasks was correlated with false memory. These findings provide evidence for a direct link between the adaptive benefits of constructive episodic processes, in the form of enhanced divergent creative thinking and problem solving, and costs, in the form of increased memory error.

Keywords False memory · Divergent thinking · Problem solving · Recall · Recognition

Introduction

Episodic memory refers to the ability to recall past personal experiences (Tulving, 2002). Episodic memory is considered a constructive process, where bits and pieces of a past event (e.g., the who, what, when, and where) are combined at the time of retrieval. These same constructive processes also leave memory prone to error and distortion, as reflected by the variety of mistaken episodic memories that can occur both in the lab and everyday life (e.g., Brainerd & Reyna, 2005; Loftus, 2003; Schacter, 2021). In one of the most extensively studied procedures for eliciting memory distortions, the Deese-Roediger-McDermott (DRM) paradigm (Deese, 1959; Roediger & McDermott, 1995; for a review, see Gallo, 2010), participants are asked to study a list of semantically related words (e.g., sugar, honey, candy, etc.) that are all related to a critical lure word that is not presented (e.g., sweet). Associative memory errors (i.e., the incorrect generation of associated/related information) occur when participants falsely claim to remember novel items that they did not study (e.g., falsely recalling or recognizing the associated critical lure, "sweet"). It has been previously argued that such memory errors can be considered "adaptive." For example, false recall and recognition in the DRM paradigm reflect, at least in part, the retention of useful information concerning the general themes or meanings that participants encountered, which can facilitate generalization and abstraction (cf., Brainerd & Reyna, 2005; Reyna et al., 2016; Schacter et al., 2011). As is well known, generalization and abstraction can support the formations of schemas (i.e.,

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organized knowledge related to the most common features of related events; Bartlett, 1932). An important question concerns the possible functions of the constructive episodic processes that lead to such memory errors.

Findings that point toward a possible answer to this question come from research indicating that episodic memory – and the constructive processes supporting it – are engaged during tasks that extend beyond simple remembering, but also involve the retrieval and reconstruction of episodic details. One such function is episodic simulation: the ability to imagine specific future and other hypothetical events (for reviews, see Schacter & Addis, 2007, 2020; Schacter et al., 2012; Schacter et al., 2017). For example, when participants are instructed to imagine a novel future event, they describe these events in greater episodic detail after receiving an episodic specificity induction (ESI), a brief training in recalling details from past episodic events (for a review, see Schacter & Madore, 2016). In addition, neuroimaging studies have found that brain regions recruited during episodic memory retrieval are also recruited during episodic simulation (for a meta-analysis, see Benoit & Schacter, 2015). These findings have been taken as support for the "constructive episodic simulation hypothesis" (Schacter & Addis, 2007, 2020). According to this hypothesis, remembering past events and imagining future events both draw on similar constructive episodic processes, which allow for the reconstruction of past experiences as well as the construction of novel future and other hypothetical experiences.

Related research has provided evidence for an even broader role of constructive episodic processing, demonstrating that it contributes to functions such as divergent creative thinking and means-end problem solving. Divergent thinking is a type of creative thinking that involves combining diverse types of information to generate novel ideas (Guilford, 1967). Divergent thinking is commonly assessed with the Alternative Uses Task (AUT; Guilford, 1967), where participants are presented with a given object word (e.g., "brick") and asked to generate alternative uses for the item (e.g., using a brick as a paperweight). Studies have shown that the ESI, relative to various control inductions, boosts subsequent performance on the AUT (Madore et al., 2015; Madore et al., 2016). The ESI has also been shown to boost performance on the Means-End Problem Solving (MEPS) task (e.g., Madore & Schacter, 2014). In the MEPS task (Platt & Spivack, 1975), participants are given a vignette of a social problem (e.g., "Mrs. P came home after shopping and found that she had lost her watch. She was very upset about it. The story ends with Mrs. P finding her watch and feeling good about it.") and asked to generate steps to reach the provided solution (e.g., "Mrs. P looks through her purse," "Mrs. P drives back to the shopping area," etc.). After receiving an ESI, participants generate more steps that are relevant to solving the problem than after a control induction (see also, Jing et al., 2016). These findings suggest that divergent thinking and problem solving draw on the constructive episodic processes that are affected by the ESI. In addition to this ESI evidence, older adults, who generate fewer episodic details when remembering past episodes and imagining future episodes (e.g., Addis et al., 2008), also generate fewer relevant steps in the MEPS task relative to younger adults, and this age-related decrease is correlated with the age-related reduction in recalling episodic details from past autobiographical experiences (Sheldon et al., 2011).

Importantly, the constructive episodic simulation hypothesis states that the flexible episodic retrieval and recombination processes that support adaptive functions, such as episodic simulation, divergent thinking, and means-end problem solving, also contribute to memory errors (e.g., Schacter & Addis, 2007, 2020; Schacter et al., 2011). A number of recent studies have provided evidence to link memory errors with adaptive functions of episodic memory, such as imagining future experiences (Dewhurst et al., 2016) and making associative inferences that link related episodes (Carpenter & Schacter, 2017, 2018). In addition to the benefits of the ESI on future imagining, divergent thinking, and means-end problem solving (see above), the ESI has been shown to boost rates of false recall in the DRM paradigm (Thakral et al., 2019). Related studies have shown that priming individuals with critical lures in the DRM paradigm can enhance performance on insight-based problem solving and analogical reasoning tasks (e.g., Howe et al., 2011; Howe et al., 2015).

Of direct relevance to the current study, Thakral et al. (2021), employed an individual differences paradigm to examine whether false memory in the DRM paradigm is *directly* linked to the number of creative uses participants generate on the AUT. Both false recall and false recognition were positively associated with *quantitative* metrics of divergent thinking (e.g., number of uses generated), but not *qualitative* metrics (e.g., the originality/creativity of uses). These findings suggest the existence of a common constructive memory system supporting both false memory and divergent creative thinking.

The current study

The results of Thakral et al. (2021) are limited in that they only link the production of memory errors to divergent thinking. As reviewed above, there is now an increasing body of evidence to indicate that means-end problem solving draws on constructive episodic memory processes. The current study had two primary goals. Given the novelty of our previous findings linking AUT performance and DRM memory errors, our first goal was to replicate the significant relationships found in Thakral et al. (2021) between false memory (recall and recognition), as assessed in the DRM paradigm, and divergent thinking, as assessed in the AUT. Our second goal was to assess whether, akin to divergent thinking, means-end problem solving draws on the same constructive episodic processes that lead to memory errors in the form of false memory (i.e., the presence of a positive correlation between rates of false recall/recognition in the DRM paradigm, and steps generated in the MEPS task).

We have four main hypotheses: (1) Quantitative divergent thinking scores would be positively associated with rates of false recall and false recognition, but that there would be no significant relationship between qualitative divergent thinking and false memory, replicating the findings from Thakral et al. (2021). The AUT was scored both as a function of the *quantity* or number of uses generated (i.e., fluency) as well as the *quality* of uses generated (e.g., ratings of creativity). In our prior work, the effect of the ESI on boosting divergent thinking was specific to quantitative metrics of creativity (Madore et al., 2015, 2016, 2019). These findings suggest that the contribution of flexible episodic processing on divergent thinking is specific to generative metrics of creativity, such as fluency. Replicating Thakral et al. (2021), we predicted that the link between flexible episodic processes that contribute to creative thinking and to false memory susceptibility would be observed when scoring the AUT for quantitative metrics. (2) There would be a novel and positive association between the relevant steps (i.e., effective steps to reach a plausible solution) generated in the MEPS task and false recall. This prediction is motivated by prior evidence indicating that the ESI boosts both means-end problem solving and false recall, suggesting that they draw on common episodic processes. (3) Divergent thinking and means-end problem solving would differ with respect to their relationship to false recognition. In Thakral et al. (2021), divergent thinking was positively correlated with both false recognition and recall. As false recall and recognition can be supported by differing processes (e.g., Schacter et al., 1998), Thakral et al. (2021) argued that the relationship between divergent thinking and both false recognition and false recall reflected gist-based/semantic retrieval (e.g., retrieval of semantic associations) leading to false recognition, and recollection-related processes (e.g., pattern completion) leading to false recall, respectively. These findings align with theoretical proposals regarding divergent creative thinking suggesting that performance in the AUT is supported by *both* semantic and episodic processes (e.g., Beaty et al., 2018; Beaty et al., 2020; Fink et al., 2015). With respect to means-end problem solving, it is unknown whether performance on the MEPS task is driven, in part, by gist-based/semantic retrieval mechanisms like those engaged during false recognition, and therefore may or may not be correlated with false recognition. Related to this point, in our prior work on the MEPS task (Jing et al., 2016), we have theorized that performance on the MEPS task recruits episodic simulation-related processes (e.g., when generating steps for a problem scenario, participant may imagine a problem-related event) that may also be linked with memory distortion. Therefore, the link between MEPS performance and false recall may be attributable to shared episodic event construction/simulation processes. Such findings would suggest that performance in the AUT and the MEPS task is supported by common distortion-related memory processes. (4) Akin to divergent thinking, means-end problem solving would not be linked to true memory (recall and recognition) on the DRM. Such findings would converge with our prior ESI evidence showing that the induction facilitates false but not true recall (Thakral et al., 2019).

Experiment 1

Materials and methods

Participants

The Institutional Review Board of Harvard University approved the experimental protocol and informed consent was obtained before participation. Seventy-seven participants were recruited through Amazon Mechanical Turk and completed the study. The sample size was restricted to participants living in the USA within the ages of 18 and 25 years. Participants had a HIT (Human Intelligence Task) approval rate greater than 95%. The experiment was administered using the online survey platform Qualtrics and participants were compensated $4.50 for completing the study. Twenty-five participants were excluded, leaving a total of 52 participants for analysis (mean (± 1 standard error) age 25.01 ± 0.23; 29 females). Seven participants were excluded for task noncompliance (e.g., not following instructions on AUT or MEPS task, generating unintelligible responses), 15 participants were excluded for self-reported cheating, one participant was excluded for producing greater than two standard deviations above the mean number of irrelevant steps on the MEPS task, and two participants were excluded for producing greater than two standard deviations above the mean number of intrusions on the DRM recall task (for similar exclusion criteria, see Thakral et al., 2021). No participants were excluded post hoc contingent on the outcome of statistical tests so as not to inflate the Type-I error rate. The analyzed sample of 52 participants was chosen a priori to match the number of participants analyzed in the previous study of Thakral et al. (2021), which served as the basis of the present study (see also Dewhurst et al., 2011). The number of excluded participants is much higher than our previous work (e.g., < 4% for self-reported cheating; Thakral et al., 2021), Of importance, we replicated the primary findings of Thakral et al. (2021; i.e., the positive correlation between false recall and recognition to quantitative divergent thinking, see below for more details). The replicable findings across the present and prior data indicate that rates of exclusion had no significant impact on the results.

Stimuli and task

Participants completed the following tasks: (a) DRM word list encoding, (b) distractor task, (c) recall test for the DRM lists, (d) recognition test for the DRM lists, (e) the AUT, and (f) the MEPS task.

a) *DRM encoding*. During the encoding phase, participants were presented with eight lists of semantically related words that were each related to a critical lure word that was not presented. Participants were instructed to remember the words for a later memory test. Each list contained 12 semantically related words (96 total words). Each word was presented for 2 s. A total of 16 lists were used, which were broken down into two sets of eight lists each, one set serving as studied items (i.e., were presented during encoding), and the other serving as non-studied items (i.e., were not presented during encoding). The assignment of list sets was counterbalanced across participants; the counterbalance groups were randomized and an equal number of participants was assigned to each group. One set of lists corresponded to the following critical lures: *slow, needle, sleep, sweet, mountain, car, anger,* and *smell*. The other set corresponded to the following critical lures: *city, chair, pen, foot, smoke, window, trash,* and *spider*. The two sets of lists were statistically equated in their likelihood of eliciting false recognition and false recall ($ps > 0.20$; Stadler et al., 1999).

b) *Distractor task*. Following encoding of word lists, participants next completed a single-letter cancellation task (i.e., a distractor task) for 1 min. They were presented with a 12 × 13 array of letters and asked to select all occurrences (52 of the 156 letters) of the letter B.

c) *DRM recall*. Participants were instructed to type as many words as they could remember, with the instructions to be "reasonably sure" that any word they recalled was presented during the previous encoding phase. The recall phase was self-paced.

d) *DRM recognition*. During the recognition task, participants were presented an 8 × 4 array of words and instructed to read each word carefully and select those words they thought were presented during the prior encoding phase. The 32 words were comprised of: eight words from the lists shown during encoding (one word randomly selected from each list; i.e., studied words), eight critical lures from each of the lists shown during encoding (i.e., studied critical lure words), eight words from the lists not shown during encoding (one word randomly selected from each list; i.e., non-studied words), and eight critical lures from the lists not shown during encoding (i.e., non-studied/critical lures). Allocation of word type to array position was randomized. Akin to the recall phase, the recognition test was also self-paced.

e) *AUT*. Participants were presented with a single object word ("brick") and instructed to type as many possible uses for the object as they could generate. They were given an example object ("notebook") with example creative uses (e.g., "use the paper in the notebook as kindling for a fire," "use the notebook to swat a fly," etc.). There were 20 empty slots for participants to write as many uses as they could. Participants had eight minutes to generate as many uses as possible.

f) *MEPS task*. Participants were presented with two social problems with a given solution. They were instructed to generate and type steps for the problem scenario that would lead the protagonist to the presented solution. There were two MEPS problems and participants were given five minutes per problem to generate steps (10 min total). Four problem sets were taken from Madore and Schacter (2014), which were originally developed by Platt and Spivack (1975).[1] Two sets of two problem scenarios were counterbalanced across participants. In the instructions for this task, an example problem (e.g., *Mrs. P came home after shopping and found that she had lost her watch. She was very upset about it.*) and solution (e.g., *The story ends with Mrs. P finding her watch and feeling good about it. You begin the story where Mrs. P found that she had lost her watch.*) were presented with example steps to reach that solution (e.g., "*look through purse and car to see if the watch is there; call the stores Mrs. P attended to see if they have the*

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[1] ***Problem 1*** (counterbalance 1): *Problem:* B needed money badly. The story begins one day when she notices a valuable diamond in a shop window. B decides to steal it. *Solution:* The story ends when B succeeds in stealing the diamond. You begin the story when B sees the diamond. ***Problem 2*** (counterbalance 1): *Problem:* J noticed that her friends seemed to be avoiding her. J wanted to have friends and be liked. *Solution:* The story ends when J's friends like her again. You begin the story where J first notices her friends avoiding her. ***Problem 1*** (counterbalance 2): *Problem:* One day G was standing around with some other people when one of them said something very nasty to G. G got very mad. G got so mad she decided to get even with the other person. *Solution:* The story ends with G happy because she got even. You begin the story when G decided to get even. ***Problem 2*** (counterbalance 2): *Problem:* C had just moved in that day and didn't know anyone. C wanted to have friends in the neighborhood. *Solution:* The story ends with C having many good friends and feeling at home in the neighborhood. You begin the story with C in her room immediately after arriving in the neighborhood.

watch"). The problem scenarios were chosen such that each counterbalanced set included a problem with deviant behavior (e.g., stealing a diamond or getting revenge) and a problem with making or restoring a relationship (e.g., making new friends or reconciling with friends).

Following completion of the MEPS, participants completed a demographic questionnaire and were probed for possible cheating via two questions: first, whether they wrote down any of the words during the encoding phase to use on the later memory test, and second, whether they used the internet (e.g., Google) to look up any answers. Participants were instructed that a "yes" response to either question did not affect compensation. If participants answered "yes" to either question, they were excluded from the analysis. This procedure of assessing self-reported cheating at the end of the experiment is consistent with prior studies that have conducted online data collection (e.g., Pennycook et al., 2018; Thakral et al., 2021). Our procedure for data exclusion based on screening procedures after experiment completion is consistent with prior best practices and recommendations for online data collection (Thomas & Clifford, 2017).

Scoring and analysis

Memory responses from the DRM paradigm were scored for recall and recognition. True recall was scored as the proportion of studied words that were recalled. True recognition was scored as the proportion of studied words that were selected of the eight studied words presented. False recall was scored as the proportion of critical lures recalled. False recognition was scored as the proportion of critical lures selected of the eight critical lures presented.

The AUT was scored for the quality and quantity of uses generated. A single measure of qualitative divergent thinking was computed (Dewhurst et al., 2011): perceived novelty of the generated use, with scores ranging from 1 (uncreative) to 4 (most creative), with scores of 3 and 4 given to only a few generated uses per participant. Creativity scores were assigned based on frequency of a given use generated across all participant responses (Addis et al., 2016). A score of 4 was given if less than 5% of other participants generated that response, a score of 3 was given if 5–10% of other participants generated that response, 2 if 10–15% of other participants generated that response, and 1 if more than 15% of other participants generated that response. Scoring for quantitative measures included the following: *fluency* (total uses generated, excluding any repetitions), *flexibility* (number of distinct categories into which appropriate uses could be classified), *appropriateness* (a score of 1 indicates appropriate uses and a score of 0 indicates inappropriate uses), and *elaboration* (the level of detail provided, scored from 0 to 2). This scoring protocol follows prior studies also employing the AUT (Madore et al., 2015, 2016). Fluency, flexibility, appropriateness, and elaboration were collapsed into a single z-scored measure of quantitative divergent thinking (see also, Thakral et al., 2021; similar results were obtained when examining each individual quantitative measure). A single rater scored the entire AUT and we confirmed high levels of inter-rater reliability with a second rater who scored 30 responses (Cronbach's α = 0.87 for quantitative divergent thinking). Inter-rater reliability for the AUT was similar to previous studies (Madore et al., 2015; Thakral et al., 2021).

The MEPS task was scored for the number of relevant steps (effective steps that move the protagonist closer to reaching the solution) and irrelevant steps (steps that do not move the protagonist towards the provided solution). The MEPS task was also scored for internal and external details in a style analogous to the Autobiographical Interview, which measures the number of internal (i.e., episodic) and external (i.e., commentary, related facts) details comprising remembered past experiences (Levine et al., 2002). Internal details were bits of episodic information that corresponded to a relevant step and external details were pieces of off topic, semantic, or repetitive information that corresponded to an irrelevant step. This style of scoring for the MEPS task into relevant/irrelevant steps and internal/external details follows prior studies (e.g., Madore & Schacter, 2014; Sheldon et al., 2011). As with the AUT, inter-rater reliability was high across the two scorers of the MEPS task (Cronbach's α = 0.98 for relevant steps and Cronbach's α = 0.96 for internal detail), similar to previous studies (Madore & Schacter, 2014).

Correlation analyses were first run to replicate the results of Thakral et al. (2021) regarding the relationship between false memory (recall and recognition) and quantitative divergent thinking. For completeness, we ran additional correlation analyses to replicate the null relationship from Thakral et al. (2021) between qualitative divergent thinking and false memory. In a novel extension of our prior study, and in order to assess whether this relationship extends to MEPS performance, we ran additional correlation analyses testing for a relationship between false memory (recall and recognition) and performance on the MEPS task as measured by the number of relevant steps generated.[2] We also conducted correlations between true memory (recall and recognition) and both quantitative divergent thinking and relevant steps produced on the MEPS task. In addition to these correlations, we ran two simultaneous regression analyses to evaluate the ability of quantitative divergent thinking and relevant steps generated in the MEPS task to first predict

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[2] In all experiments, analyses were also conducted on the internal detail measure, and results were identical.

rates of false recognition, and second, to predict rates of false recall. We also ran two regression analyses to evaluate the ability for false recognition and false recall to first predict quantitative divergent thinking and second, to predict relevant steps generated in the MEPS task. Before regression analyses were conducted, we confirmed that there were no violations of the assumptions of multicollinearity (variance inflation factor < 5). All results are considered significant at $p < 0.05$.

Results

Complete recognition and recall data are detailed in Table 1. Rates of true, false, and distractor recognition as well as true and false recall were similar to values reported in Thakral et al. (2021). The distractor recognition rate was low, confirming recognition task compliance. Critically, the rates of true and false recall were significantly greater than 0 (ts(51) >5.54, ps < 0.001), indicating that the DRM paradigm produced reliable rates of false recall.

Creativity data from the AUT are shown in Table 2. Quantitative and qualitative metrics of AUT performance were also similar to values reported in Thakral et al. (2021). The MEPS task data are shown in Table 3. Steps and details generated in the MEPS task were similar to values found in previous in-lab uses of the MEPS task (e.g., Madore & Schacter, 2014), which demonstrates the reliability of using an online version of the MEPS task. Participants generated a greater number of relevant steps and internal details than irrelevant steps and external details, indicating that participants were task-compliant (Table 3).

False recall

Bivariate correlations between recall, divergent thinking, and problem solving are listed in Table 4. Initial correlation analyses revealed a significant positive correlation between false recall and quantitative divergent thinking (Fig. 1, left) replicating Thakral et al. (2021). False recall and qualitative divergent thinking were not correlated (Table 4), also replicating the null findings of Thakral et al. (2021). In a novel finding, we observed a significant positive relationship between false recall and MEPS relevant steps (Fig. 1, right).

We ran a simultaneous regression analysis to assess whether quantitative divergent thinking and MEPS performance predicted false recall (Table 5). The simultaneous regression revealed that quantitative divergent thinking and MEPS performance accounted for 26.7% of the variance in false recall (F (2, 49) = 8.90, $p = 0.001$). Both quantitative divergent thinking (β = 0.34, t (51) = 2.52, $p = 0.015$) and MEPS performance (β = 0.28, t (51) = 2.06, $p = 0.045$) significantly predicted false recall. This regression analysis corroborates the correlation analyses.

False recognition

Bivariate correlations between recognition, divergent thinking, and problem solving are shown in Table 6. Akin to the significant relationship between false recall and quantitative divergent thinking, correlation analyses revealed a significant and positive relationship between false recognition and quantitative divergent thinking (Fig. 2, left). These results replicate Thakral et al. (2021). Similar to false recall, false recognition was not significantly related to qualitative divergent thinking (Table 6), also consistent with the results from Thakral et al. (2021).

No significant relationship was found between false recognition and MEPS relevant steps (Fig. 2, right). Taken together, these findings suggest that means-end problem solving, in direct contrast to quantitative divergent thinking, was uniquely related to false recall and not false recognition. To test this possibility, we conducted a regression analysis to directly compare the ability of quantitative divergent thinking and MEPS performance to predict false recognition (Table 7). The simultaneous regression analysis revealed that quantitative divergent thinking and MEPS performance accounted for 22.2% of the variance in false recognition (F (2, 49) = 6.99, $p = 0.002$). Similar to the results of the correlation analyses, quantitative divergent thinking significantly predicted false recognition (β = 0.49, t (51) = 3.51, $p = 0.001$), whereas MEPS performance did not (β = - 0.04, t (51) <1). This finding is in contrast to both quantitative divergent thinking and MEPS performance, which were each significant predictors of false recall (Table 5).

True memory

As in Thakral et al. (2021), true memory (recall and recognition) was not significantly correlated with quantitative or qualitative divergent thinking (Tables 4 and 6, rs < 0.29; no correlations survived corrections for multiple comparisons).

Table 1 Mean proportion (± 1 standard error of the mean) of studied words, critical lures, and non-studied distractors (i.e., non-studied words) remembered in Experiment 1

	True recognition	False recognition	Distractor recognition	True recall	False recall
Experiment 1	0.58 (0.03)	0.58 (0.04)	0.07 (0.01)	0.22 (0.02)	0.13 (0.02)

Table 2 Mean score (± 1 standard error of the mean) for the Alternative Uses Task (AUT) in Experiment 1

AUT score (Divergent thinking)	Experiment 1
Quantitative metrics	
Fluency (total uses)	12.63 (0.75)
Flexibility (categories of appropriate uses)	6.92 (0.39)
Appropriateness (total appropriate uses)	12.46 (0.74)
Elaboration (0–2; higher = more detailed)	0.65 (0.04)
Qualitative metric	
Originality (1–4, higher = more original and infrequent)	2.06 (0.06)

Table 3 Mean score (± 1 standard error of the mean) for the Means-End Problem Solving (MEPS) task in Experiment 1

Problem-solving score	Experiment 1
Relevant steps	9.21 (0.60)
Internal details	31.73 (2.01)
Irrelevant steps	0.63 (0.15)
External details	2.17 (0.57)

Analogous to divergent thinking, relevant steps generated in the MEPS task were also not correlated with true recall or recognition (Tables 4 and 6, rs < 0.07). Regression analyses were not performed on these data as the correlations were not significant.

Discussion

The results of Experiment 1 revealed that better quantitative divergent thinking performance predicted increased false recognition and false recall, replicating Thakral et al. (2021). In addition, we also found for the first time that increased problem-solving ability (measured via relevant steps produced on the MEPS task) was associated with increased false memory. In contrast to divergent thinking, this relationship was specific to false recall. These findings suggest that performance in both the AUT and the MEPS task is supported by distortion-related episodic memory processes that lead to increased false recall.

The primary goal of Experiment 2 was to investigate whether the link between false recall and MEPS performance was specific to problem solving as operationalized through the MEPS task, or whether these findings extend to other forms of problem solving. To examine this question, we used the Everyday Descriptions Task (EDT; Vandermorris et al., 2013). Like the MEPS task, the EDT requires the generation of target responses (i.e., relevant steps). However, in contrast to the MEPS task, the EDT employs scenarios that participants encounter *more* frequently in everyday life (e.g., in the EDT, "*How would you organize a move to a new place to live?*" vs. in the MEPS task, "*B needed money badly. The story begins one day when she notices a valuable diamond in a shop window. B decides to steal it.*").

There is evidence to suggest that the EDT draws on episodic memory processes similar to the MEPS task. For example, in Vandermorris et al. (2013), young and older adults completed the Autobiographical Interview, MEPS task, and EDT. Relative to younger adults, older adults produced significantly fewer internal details on the Autobiographical Interview, and significantly fewer steps in the MEPS task (see also Madore & Schacter, 2014). A similar but not statistically significant age-related decrease in performance on the EDT was observed. In addition, the number of episodic details generated in the Autobiographical Interview was correlated with the number of steps generated in the EDT and MEPS task, suggesting that the generation of episodic content and effective problem solving are supported by common processes (Vandermorris et al., 2013; see also Dritschel et al., 1998). These findings lead to the prediction that the EDT relies on constructive episodic processes like those implicated in the MEPS task, and therefore may be correlated with false recall in Experiment 2, replicating the findings of Experiment 1. However, since the EDT and MEPS task are different, for example with respect to the frequency of the occurrence of the problems employed in each task (see above), there may be a different relationship between true and false memory rates and performance on the

Table 4 Bivariate correlations between recall, divergent thinking, and Means-End Problem-Solving (MEPS) task relevant steps in Experiment 1

	False recall	True recall	Qualitative divergent thinking	Quantitative divergent thinking	MEPS relevant steps
False recall	1.00	-0.06	0.16	0.45***	0.41***
True recall		1.00	-0.20	0.09	0.05
Qualitative divergent thinking			1.00	0.30*	0.29*
Quantitative divergent thinking				1.00	0.41***
MEPS relevant steps					1.00

*$p < 0.05$, **$p < 0.01$, ***$p < 0.005$; those that are $p < 0.005$ also survive a Bonferroni correction for multiple comparisons

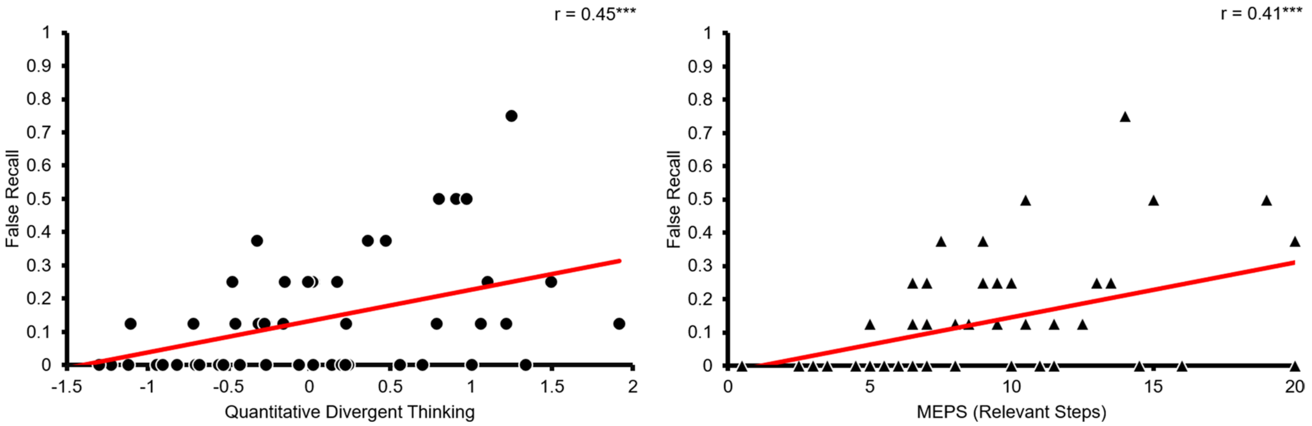

Fig. 1 Scatter plots and regression lines from Experiment 1 showing the correlations between false recall and quantitative divergent thinking (**left**), and false recall and relevant steps produced in the Means-End Problem-Solving (MEPS) task (**right;** *$p < 0.05$, **$p < 0.01$, ***$p < 0.005$; those that are $p < 0.005$ also survive a Bonferroni correction for multiple comparisons)

Table 5 Summary of the regression analysis for quantitative divergent thinking and relevant Means-End Problem-Solving (MEPS) steps in relation to false recall (*$p < 0.05$) in Experiment 1

	B	SE B	β
Constant	0.03	0.05	
Quantitative divergent thinking	0.07	0.03	0.34*
Relevant MEPS steps	0.01	0.005	0.28*

two problem-solving tasks to suggest that the EDT and MEPS task may draw on differential episodic processes.

Experiment 2

Materials and methods

Participants

One hundred and eleven participants were recruited through Amazon Mechanical Turk and completed the study. Sixty participants were excluded for a total of 51 participants for analysis (mean ± (1 standard error) age 25.02 ± 0.37 years; 27 females). Eight participants were excluded for task noncompliance (e.g., not following instructions on AUT or EDT), 45 participants were excluded for self-reported cheating, four participants were excluded for producing greater than two standard deviations above the mean number of irrelevant steps on the EDT, and three participants were excluded for producing greater than two standard deviations above the mean number of intrusions on the DRM recall task.

Stimuli and task

The methods of Experiment 2 were identical to the methods of Experiment 1 (DRM encoding, distractor task, DRM recall, DRM recognition, and AUT) with the exception that the MEPS task was replaced by the EDT. We included the AUT primarily to keep the procedure identical to that of Experiment 1, but also to achieve yet another replication of our previous findings. In the EDT, participants were presented with two social problems typically encountered

Table 6 Bivariate correlations between recognition, divergent thinking, and Means-End Problem Solving (MEPS) task relevant steps in Experiment 1

	False recognition	True recognition	Qualitative divergent thinking	Quantitative divergent thinking	MEPS relevant steps
False recognition	1.00	0.28*	0.18	0.47***	0.16
True recognition		1.00	0.25	0.29*	0.07
Qualitative divergent thinking			1.00	0.30*	0.29*
Quantitative divergent thinking				1.00	0.41***
MEPS relevant steps					1.00

*$p < 0.05$, **$p < 0.01$, ***$p < 0.005$; those that are $p < 0.005$ also survive a Bonferroni correction for multiple comparisons

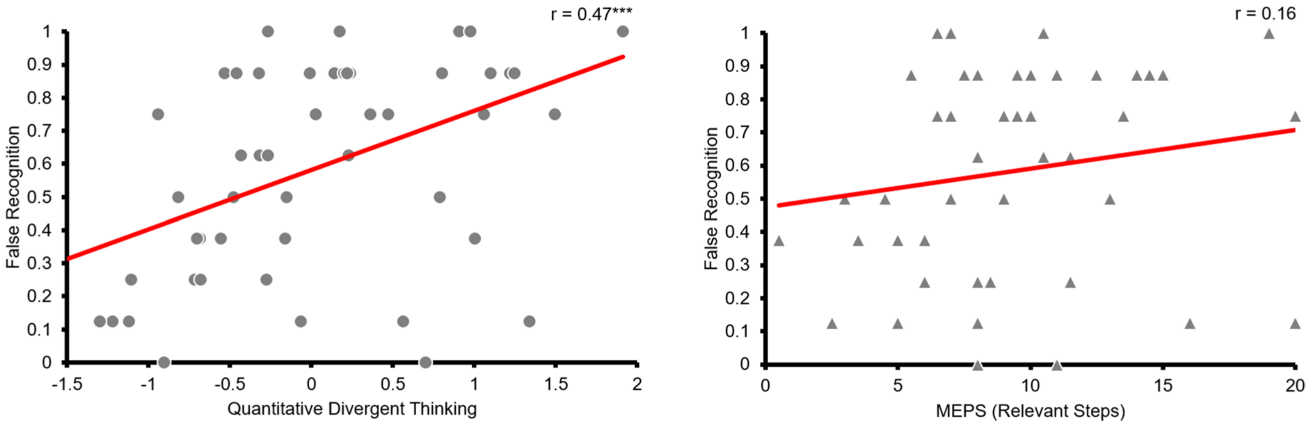

Fig. 2 Scatter plots and regression lines from Experiment 1 showing the correlations between false recognition and quantitative divergent thinking (**left**) and false recognition and relevant steps produced in the Means-End Problem-Solving (MEPS) task (**right**; *$p < 0.05$, **$p < 0.01$, ***$p < 0.005$; those that are $p < 0.005$ are also those that survive a Bonferroni correction for multiple comparisons)

Table 7 Summary of the regression analysis for quantitative divergent thinking and relevant Means-End Problem-Solving (MEPS) steps in relation to false recognition (*$p < 0.05$) in Experiment 1

	B	SE B	β
Constant	0.61	0.10	
Quantitative divergent thinking	0.18	0.05	0.49*
Relevant MEPS steps	-0.003	0.10	-0.04

in everyday life. The problems in the EDT were phrased as a question (e.g., *How would you go about planning a special day out with friends?*). Participants were given 5 min per problem to generate steps (10 min total) and were instructed to generate steps to answer the presented questions. Four problem sets were taken from Vandermorris et al. (2013), and two sets of two problem scenarios were counterbalanced across participants.[3] The four problem sets used were defined as *open-ended* problems by Vandermorris et al. (2013); originally developed by Dritschel et al., 1998). Open-ended EDT problems are designed to generate responses that are less structured, flexible in the ordering of steps, and require more planning (e.g., buying a new car). These problems are in contrast to *closed-ended* problems, where the steps needed to complete the task are well established and require few steps that are generally completed in a single order (e.g., brushing one's teeth). In the instructions for the EDT, an example problem (e.g., *"How would you organize a school reunion*?") was presented with example steps to reach that solution (e.g., *"I would start by contacting a few former classmates to help me organize it"; "We would then discuss a location to host the reunion"*).

Scoring and analysis

True and false recall and recognition responses, and AUT responses, were scored as detailed in Experiment 1. The EDT was scored using the same scoring criteria as the MEPS task, as relevant steps, irrelevant steps, internal details, and external details. This style of scoring for the EDT follows prior studies (Vandermorris et al., 2013). A single rater scored the AUT and EDT. We confirmed high levels of inter-rater reliability with a second rater who scored 30 responses for both tasks (Cronbach's α = 0.89 for quantitative divergent thinking and Cronbach's α = 0.96 and 0.95 for relevant steps and internal details on the EDT, respectively).

We ran correlation analyses to replicate the results of Experiment 1 and Thakral et al. (2021) concerning the relationship between false memory (recall and recognition) and quantitative divergent thinking. To assess whether the significant relationship between false recall and MEPS performance extends to EDT performance, we ran additional correlation analyses assessing the relationship between false memory (recall and recognition) and performance on the EDT, as assessed by the number of relevant steps generated. We also correlated EDT performance with true memory (recall and recognition) to determine whether the EDT had a differential relationship to true memory compared to the MEPS task, which was not related to true memory. As in Experiment 1, we ran simultaneous regression analyses to evaluate the ability of quantitative divergent thinking and relevant

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[3] ***Problem 1*** (counterbalance 1): How would you go about planning a special day out with friends?; ***Problem 2*** (counterbalance 1): How would you organize a move to a new place to live?; ***Problem 1*** (counterbalance 2): How would you cook a meal in order to celebrate someone's birthday?; ***Problem 2*** (counterbalance 2)***:*** How would you plan a vacation?

Table 8 Mean proportion (± 1 standard error of the mean) of studied words, critical lures, and non-studied distractors (i.e., non-studied words) remembered in Experiment 2

	True recognition	False recognition	Distractor recognition	True recall	False recall
Experiment 2	0.59 (0.04)	0.57 (0.04)	0.06 (0.01)	0.20 (0.02)	0.14 (0.03)

Table 9 Mean score (± 1 standard error of the mean) for the Alternative Uses Task (AUT) in Experiment 2

AUT score (Divergent thinking)	Experiment 2
Quantitative metrics	
Fluency (total uses)	13.41 (0.84)
Flexibility (categories of appropriate uses)	7.73 (0.40)
Appropriateness (total appropriate uses)	13.18 (0.83)
Elaboration (0–2; higher = more detailed)	0.55 (0.05)
Qualitative metric	
Originality (1–4, higher = more original and infrequent)	2.19 (0.07)

Table 10 Mean score (± 1 standard error of the mean) for the Everyday Descriptions Task (EDT) in Experiment 2

Problem solving score	Experiment 2
Relevant steps	9.72 (0.63)
Internal details	33.63 (2.51)
Irrelevant steps	0.72 (0.15)
External details	2.18 (0.44)

steps generated in the EDT task to predict rates of true and false memory.

Results

Complete recognition and recall data from Experiment 2 are listed in Table 8. Rates of distractor recognition and true and false recall and recognition were similar to values in Experiment 1 and Thakral et al. (2021). The rates of true and false recall were significantly greater than 0 (ts(50) >5.47, ps < 0.001).

Creativity data from the AUT are shown in Table 9. Quantitative and qualitative metrics of AUT performance are also similar to values in Experiment 1 and Thakral et al. (2021). The EDT results are shown in Table 10, and steps and details from the EDT were similar to values in the MEPS task from Experiment 1. Participants generated a greater number of relevant steps and internal details than irrelevant steps and external details, indicating that participants remained on-task (Table 10).

False recall

Bivariate correlations between recall, divergent thinking, and problem solving in Experiment 2 are shown in Table 11. False recall and quantitative divergent thinking were significantly and positively correlated, replicating the results from Experiment 1 and Thakral et al. (2021); Fig. 3, left). However, there was no significant relationship between false recall and the number of relevant steps generated in the EDT, unlike the relationship between false recall and MEPS relevant steps observed in Experiment 1, (Fig. 3, right). The correlation between false recall and qualitative divergent thinking (Table 11) did not survive correction for multiple comparisons, replicating the findings from Thakral et al. (2021) and Experiment 1.

We ran a simultaneous regression analysis to assess how quantitative divergent thinking and EDT relevant steps predicted false recall (Table 12). This analysis revealed that quantitative divergent thinking and EDT relevant steps

Table 11 Bivariate correlations between recall, divergent thinking, and Everyday Descriptions Task (EDT) relevant steps in Experiment 2

	False recall	True recall	Qualitative divergent thinking	Quantitative divergent thinking	EDT relevant steps
False recall	1.00	0.15	0.32*	0.42***	0.21
True recall		1.00	-0.20	0.10	0.21
Qualitative divergent thinking			1.00	0.46***	0.35*
Quantitative divergent thinking				1.00	0.52***
EDT relevant steps					1.00

**p* < 0.05, ***p* <0.01, ****p* < 0.005; those that are *p* < 0.005 also survive a Bonferroni correction for multiple comparisons

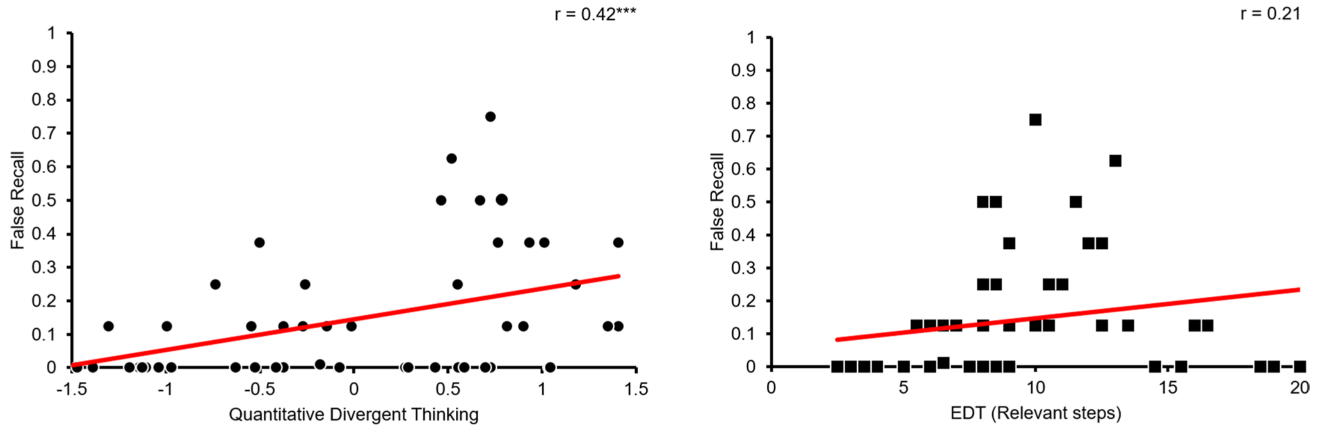

Fig. 3 Scatter plots and regression lines from Experiment 2 showing the correlations between false recall and quantitative divergent thinking (**left**) and false recall and relevant steps produced in the Everyday Descriptions Task (EDT) (**right**). *$p < 0.05$, **$p < 0.01$, ***$p < 0.005$; those that are $p < 0.005$ survive a Bonferroni correction for multiple comparisons

Table 12 Summary of the regression analysis for quantitative divergent thinking and relevant Everyday Descriptions Task (EDT) steps in relation to false recall (*$p < 0.05$) in Experiment 2

	B	SE B	β
Constant	0.15	0.07	
Quantitative divergent thinking	0.09	0.03	0.42*
Relevant EDT steps	0.0	0.01	-0.01

accounted for 17.2% of the variance in false recall (F (2, 48) = 5.00, $p = 0.01$). Paralleling the correlation analyses, quantitative divergent thinking significantly predicted false recall (β = 0.42, t (50) = 2.74, $p = 0.01$), whereas EDT performance was not a significant predictor of false recall (β = -0.01, t (50) <1).

False recognition

Bivariate correlations between recognition, divergent thinking, and problem solving are shown in Table 13. As with false recall, false recognition and quantitative divergent thinking were significantly and positively correlated, replicating the results from Experiment 1 and Thakral et al. (2021) (Fig. 4, left). False recognition and qualitative divergent thinking were not significantly correlated, replicating the findings from Thakral et al. (2021) and Experiment 1 (Table 13). There was a positive relationship between false recognition and EDT relevant steps; however, this correlation did not survive correction for multiple comparisons (Fig. 4, right).

Paralleling the regression analysis in Experiment 1, we conducted a set of regression analyses to directly compare the unique ability of quantitative divergent thinking, but not EDT performance, to predict false recognition (Table 14). This analysis revealed that quantitative divergent thinking and EDT relevant steps accounted for 21.2% of the variance in false recognition (F (2, 48) = 6.45, $p = 0.003$). Consistent with the correlation analyses, quantitative divergent thinking significantly predicted false recognition (β = 0.36, t (50) = 2.42, $p = 0.02$), whereas EDT performance did not (β = 0.15, t (50) = 1.02, $p = 0.31$).

Table 13 Bivariate correlations between recognition, divergent thinking, and Everyday Descriptions Task (EDT) relevant steps in Experiment 2

	False recognition	True recognition	Qualitative divergent thinking	Quantitative divergent thinking	EDT relevant steps
False recognition	1.00	0.39***	0.28*	0.44***	0.34*
True recognition		1.00	0.09	0.20	0.38**
Qualitative divergent thinking			1.00	0.46***	0.35*
Quantitative divergent thinking				1.00	0.52***
EDT relevant steps					1.00

*$p < 0.05$, **$p < 0.01$, ***$p < 0.005$; those that are $p < 0.005$ also survive a Bonferroni correction for multiple comparisons

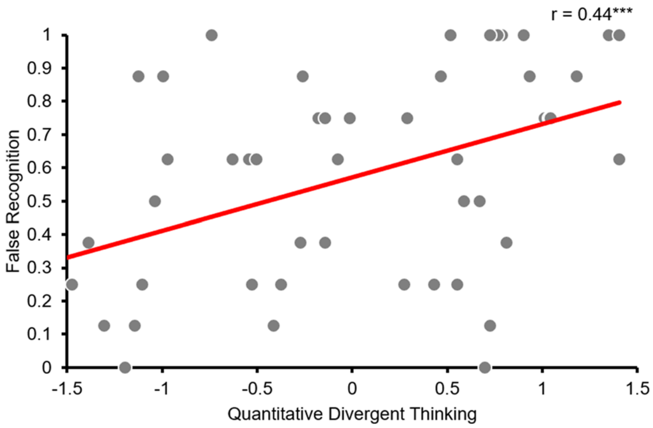

Fig. 4 Scatter plots and regression lines from Experiment 2 showing the correlations between false recognition and quantitative divergent thinking (**left**) and false recognition and relevant steps produced in the Everyday Descriptions Task (EDT) (**right**). *$p < 0.05$, **$p < 0.01$, ***$p < 0.005$; those that are $p < 0.005$ also survive a Bonferroni correction for multiple comparisons

Table 14 Summary of the regression analysis for quantitative divergent thinking and relevant Everyday Descriptions Task (EDT) steps in relation to false recognition (*$p < 0.05$) in Experiment 2

	B	SE B	β
Constant	0.47	0.11	
Quantitative divergent thinking	0.13	0.06	0.36*
Relevant EDT steps	0.01	0.01	0.15

True memory

There was no significant correlation between true memory (recall or recognition) and qualitative or quantitative divergent thinking, replicating Experiment 1 and Thakral et al. (2021) (Tables 11 and 13). Akin to divergent thinking and MEPS performance, the correlation between true recall and EDT relevant steps was also not significant (Fig. 5, left). We did not run a regression analysis for true recall and EDT relevant steps as the correlations were null.

In contrast to the both the AUT and MEPS task, the correlation between true recognition and EDT performance was significant (Fig. 5, right). We ran a simultaneous regression with true recall and true recognition as predictors of EDT relevant steps (Table 15). This analysis revealed that true recall and true recognition accounted for 14.6% of the variance in EDT relevant steps (F (2, 48) = 4.09, $p = 0.02$). While true recognition was a significant predictor of EDT relevant steps (β = 0.28, t (50) = 2.38, $p = 0.02$), true recall was not (β = 0.01, t (50) <1).

We performed a final regression analysis to determine if relevant EDT steps, but not quantitative divergent thinking, was a significant predictor of true recognition (Table 16). This analysis revealed that quantitative divergent thinking

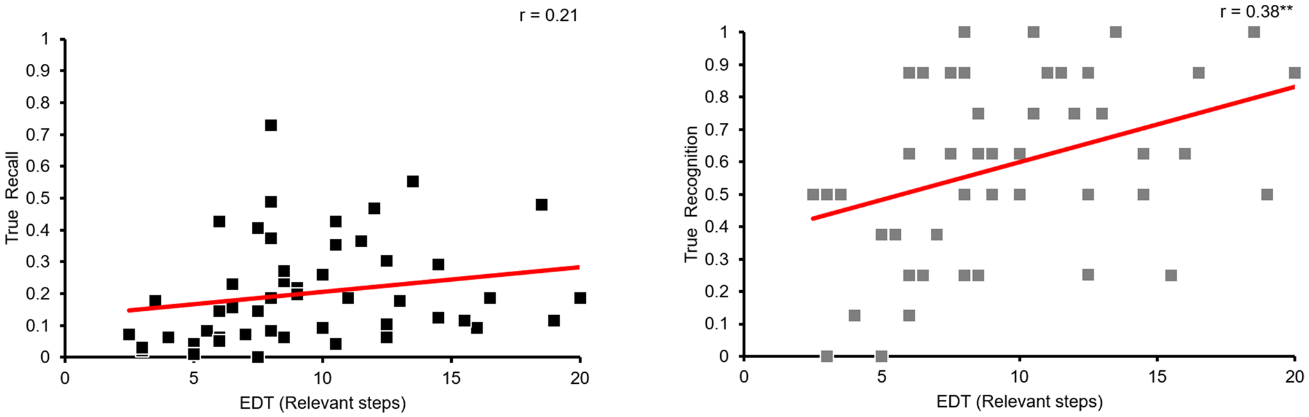

Fig. 5 Scatter plots and regression lines from Experiment 2 showing the correlations between true recognition and relevant steps produced in the Everyday Descriptions Task (EDT) (**left**) and true recall and relevant steps produced in the EDT (**right**). *$p < 0.05$, **$p < 0.01$, ***$p < 0.005$; those that are $p < 0.005$ are also those that survive a Bonferroni correction for multiple comparisons

Table 15 Summary of the regression analysis for true recall and true recognition in relation to Everyday Descriptions Task (EDT) relevant steps (*$p < 0.05$) in Experiment 2

	B	SE B	β
Constant	6.00	1.43	
True recall	0.36	4.39	0.01
True recognition	6.14	2.59	0.38*

Table 16 Summary of the regression analysis for quantitative divergent thinking and relevant Everyday Descriptions Task (EDT) steps in relation to true recognition (*$p < 0.05$) in Experiment 2

	B	SE B	β
Constant	0.37	0.10	
Quantitative divergent thinking	0.00	0.05	-0.001
Relevant EDT steps	0.02	0.01	0.38*

and EDT relevant steps accounted for 14.6% of the variance in true recognition (F (2, 48) = 4.09, $p = 0.02$). EDT performance was the sole significant predictor of true recognition (β = 0.38, t (50) = 2.45, $p = 0.02$).

Discussion

In Experiment 2, we replicated the findings of Thakral et al. (2021) and Experiment 1 where both false recall and false recognition were positively related to quantitative divergent thinking. However, the relationship between problem-solving performance in the MEPS task and false recall observed in Experiment 1 did not extend to problem-solving performance assessed with the EDT. In contrast, increased performance on the EDT was related to increased true recognition in the DRM paradigm. These latter findings would suggest that performance in the EDT is not supported by the same distortion-related episodic memory processes as those engaged in the MEPS task.

In Experiment 3, we attempt to directly replicate the positive link between false recall and MEPS performance seen in Experiment 1, but without prior administration of the AUT. A secondary aim of Experiment 3 was to test whether there were experimental conditions under which the EDT would draw on distortion-related episodic processes and therefore be linked to false memory akin to the MEPS task. We accomplished this objective by using a within-participants design where the MEPS task was followed by the EDT. We hypothesized that by having participants complete the MEPS task before the EDT, they would more likely use the same kind of episodic problem-solving strategy as that employed in the MEPS task, and therefore recruit the same distortion-related episodic processes to generate steps in the EDT task as they did on the MEPS task.

Experiment 3

Materials and methods

Participants

One hundred and twenty-three participants were recruited through Amazon Mechanical Turk and completed the study. Seventy-one participants were excluded for a total of 52 participants for analysis (mean ± (1 standard error) age 25.41 ± 0.25 years; 22 females, one person self-reported as being agender). Twenty-five participants were excluded for task noncompliance (e.g., not following instructions on the MEPS task or EDT), 40 participants were excluded for self-reported cheating, four participants were excluded for producing greater than two standard deviations above the mean number of irrelevant steps on the EDT or MEPS task, and two participants were excluded for producing greater than two standard deviations above the mean number of intrusions on the DRM recall task.

Stimuli and task

The methods of Experiment 3 were identical to the methods of Experiment 2 (DRM encoding, distractor task, DRM recall, and DRM recognition) with the exception that the AUT task was replaced by the MEPS task, which was directly followed by the EDT. The problem sets chosen for the EDT and MEPS task were the same as those used in Experiments 1 and 2, and were similarly counterbalanced.

Scoring and analysis

Memory data, MEPS responses, and EDT responses were scored as detailed in Experiments 1 and 2 above. A single rater scored the MEPS and EDT responses. We confirmed high levels of inter-rater reliability with a second rater who scored 30 responses (Cronbach's α > 0.90 for relevant steps and internal details on the MEPS task and EDT, respectively).

We ran correlation analyses to replicate the results of Experiment 1 concerning the relationship between false recall and performance in the MEPS task, and to assess whether EDT performance would also be correlated to false memory. We also ran simultaneous regression analyses to evaluate the ability of performance in the MEPS and/or EDT to predict rates of true and false memory.

Results

Complete recognition and recall data from Experiment 3 are listed in Table 17. Rates of distractor recognition and true memory and false recall were similar to values in

Table 17 Mean proportion (± 1 standard error of the mean) of studied words, critical lures, and non-studied distractors (i.e., non-studied words) remembered in Experiment 3

	True recognition	False recognition	Distractor recognition	True recall	False recall
Experiment 3	0.54 (0.03)	0.38 (0.04)	0.09 (0.01)	0.26 (0.03)	0.10 (0.02)

Table 18 Mean score (± 1 standard error of the mean) for the Means-End Problem-Solving (MEPS) task and Everyday Descriptions Task (EDT) in Experiment 3

	Experiment 3 (MEPS)	Experiment 3 (EDT)
Relevant steps	7.25 (0.66)	7.68 (0.47)
Internal details	25.52 (2.57)	28.53 (2.42)
Irrelevant steps	1.40 (0.16)	1.25 (0.17)
External details	3.91 (0.50)	3.76 (0.51)

Experiments 1 and 2. Rates of false recognition (0.38) were somewhat smaller than Experiments 1 and 2 (where rates of false recognition were > 0.57). Rates of true and false recall were significantly greater than 0 (ts(51) >5.03, ps < 0.001).

Performance in the MEPS task and EDT from Experiment 3 are shown in Table 18. Steps and details from the MEPS task and EDT were similar in magnitude to Experiment 1 and Experiment 2, respectively. Participants generated a greater number of relevant steps and internal details than irrelevant steps and external details, indicating that participants remained on-task for both the MEPS task and EDT (Table 18).

False recall

Bivariate correlations between recall and problem solving for both tasks in Experiment 3 are shown in Table 19. Replicating the results from Experiment 1, the correlation analysis between false recall and performance in the MEPS task revealed a significant and positive correlation (Fig. 6, left). EDT performance was also positively correlated with false recall (Fig. 6, right), in contrast to Experiment 2. Due to the high collinearity between MEPS and EDT performance (r = 0.76), we did not perform regression analyses where both variables were entered as predictors of false recall.

False recognition

Bivariate correlations between recognition and problem solving for both tasks in Experiment 3 are shown in Table 20. False recognition was positively correlated with performance in both the MEPS task (Fig. 7, left) and EDT (Fig. 7, right), in contrast to Experiments 1 and 2. As with the false recall analysis, due to the high collinearity between MEPS and EDT performance, we did not perform regression analyses where both variables were entered as predictors of false recognition.

True memory

True recall was not significantly correlated with performance on either the MEPS task or EDT (see Tables 19 and 20). Although true recognition was correlated with problem-solving performance in both tasks, it did not survive correction for multiple comparisons. As the correlation analyses were null, further regression analyses were not run on these data.

General discussion

In this study we examined the link between memory distortion (in the form of false memories in the DRM paradigm) and the adaptive functions of divergent thinking and problem solving across three experiments. In Experiments 1 and 2 we replicated the results of Thakral et al. (2021), finding a significant and positive relationship between false recall and quantitative

Table 19 Bivariate correlations between recall, Means-End Problem-Solving (MEPS) task relevant steps, and Everyday Descriptions Task (EDT) relevant steps in Experiment 3

	False recall	True recall	MEPS relevant steps	EDT relevant steps
False recall	1.00	-0.17	0.41***	0.47***
True recall		1.00	0.12	0.10
MEPS relevant steps			1.00	0.76***
EDT relevant steps				1.00

*$p < 0.05$, **$p < 0.01$, ***$p < 0.005$; those that are $p < 0.005$ also survive a Bonferroni correction for multiple comparisons

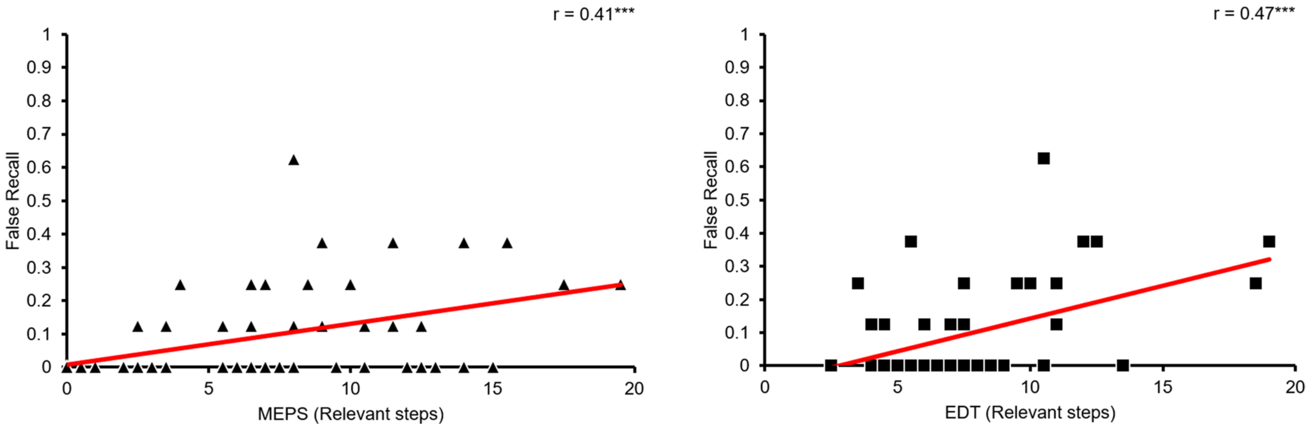

Fig. 6 Scatter plots and regression lines from Experiment 3 showing the correlations between false recall and relevant steps produced in the Means-End Problem-Solving (MEPS) task (**left**) and Everyday Descriptions Task (EDT) (**right**). *p < 0.05, **p < 0.01, ***p <0.005; those that are p < 0.005 also survive a Bonferroni correction for multiple comparisons

Table 20 Bivariate correlations between recognition, Means-End Problem-Solving (MEPS) relevant steps, and Everyday Descriptions Task (EDT) relevant steps in Experiment 3

	False recognition	True recognition	MEPS relevant steps	EDT relevant steps
False recognition	1.00	0.00062	0.50***	0.52***
True recognition		1.00	0.28*	0.29*
MEPS relevant steps			1.00	0.76***
EDT relevant steps				1.00

*$p < 0.05$, **$p < 0.01$, ***$p < 0.005$; those that are $p < 0.005$ also survive a Bonferroni correction for multiple comparisons

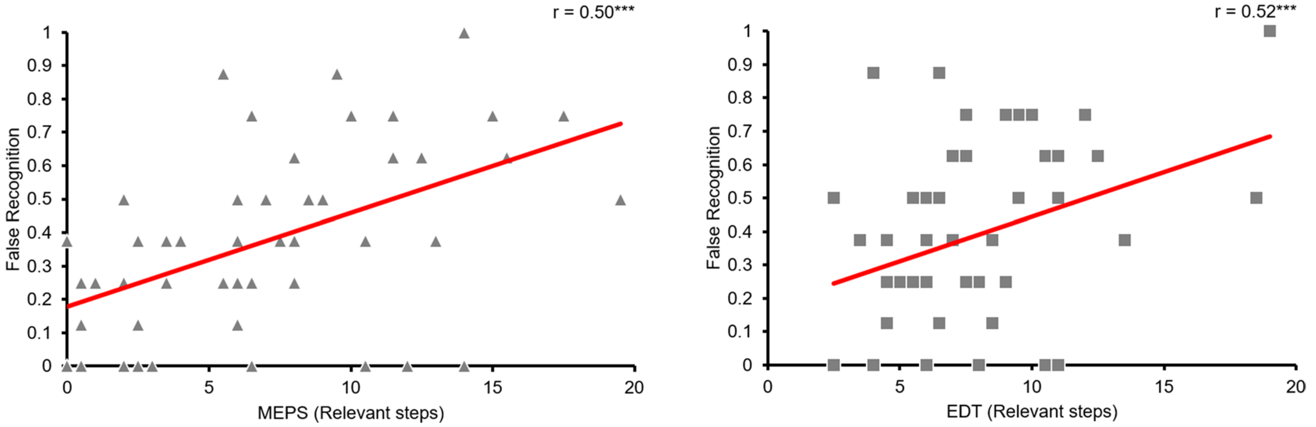

Fig. 7 Scatter plots and regression lines from Experiment 3 showing the correlations between false recognition and relevant steps produced in the Means-End Problem-Solving (MEPS) task (**left**) and Everyday Descriptions Task (EDT) (**right**). *p < 0.05, **p < 0.01, ***p <0.005; those that are p < 0.005 also survive a Bonferroni correction for multiple comparisons

divergent thinking as well as false recognition and quantitative divergent thinking (as measured in the AUT). Critically, in Experiment 1 we also identified a novel link between increased false recall, but not false recognition, and the number of relevant steps produced during a means-end problem-solving task (i.e., the MEPS task). In Experiment 2, we tested whether the relationship between MEPS task performance and false recall extends to another form of problem solving previously linked with episodic processing (i.e., the EDT). However, we found no link between EDT performance and false memory (recall or recognition). Moreover, in contrast to both the MEPS task and AUT, true recognition was predicted by relevant steps produced in the EDT. Finally, in Experiment 3, we replicated our novel finding of a link between increased false memory and MEPS performance observed in Experiment 1. We further showed that problem solving in the EDT can be positively correlated with false memory when conditions encouraged participants to recruit the same task strategy as the MEPS (i.e., when the EDT follows the MEPS task). We discuss the implications of these findings below.

Links between episodic memory processing and the MEPS task

Similar to the AUT, false recall was positively correlated with performance in the MEPS task. As discussed in Thakral et al. (2021), this link between the AUT and false recall may reflect the episodic memory process of pattern completion. Pattern completion refers to the reinstatement of a partially overlapping set of retrieved event features that spreads to the rest of the event features. False recall results from failures in pattern completion such as the construction of an incorrect retrieval cue (Schacter et al., 1998). For example, reliance on gist-based retrieval cues may lead to false recall in the DRM paradigm. Like the AUT, pattern completion may also support performance in the MEPS task. That is, in the MEPS task participants may internally generate and retrieve specific details that support the generation of steps to solve an open-ended social problem, just as they support generation of a creative use on the AUT.

In contrast to the association between the AUT and both types of false memory (i.e., recall and recognition), in Experiment 1, the link between MEPS performance and false memory was specific to false recall and not false recognition. The AUT, and divergent creative thinking in general, is supported by both episodic processing and semantic processing (e.g., Beaty et al., 2018, 2020; Hass, 2017; Madore et al., 2017; Wu et al., 2015), which we have suggested underlies its association with both false recall and recognition, respectively (see Thakral et al., 2021, for further discussion). Under the assumption that recall is a more process-pure measure of episodic processing relative to recognition (Yonelinas, 2002), the differential relationship between problem solving and false recall versus recognition may reflect the greater reliance of episodic processing during the MEPS task. In line with this proposal, Jing et al. (2016) suggested that completion of the MEPS task may invoke simulation-based processes. For example, participants may construct and then simulate a given problem scenario in order to generate steps. Similarly, generating a recalled item in the DRM task may be completed by reconstructing and then simulating the encoding presentation and inadvertently recalling a critical lure item (i.e., content/context borrowing; Lampinen et al., 2005; O'Neill & Diana, 2017). As such, the link between MEPS performance and false recall may be due to shared episodic event construction/simulation processes.

In Experiment 3, the positive link between false recall and performance in the MEPS task was replicated. Surprisingly, however, performance in the MEPS task was also positively correlated with false recognition. One possible reason for the discrepancy between Experiments 1 and 3 is the overall difference in rates of false recognition. In contrast to the rates of false recall, which were very similar across experiments (0.13 vs. 0.10), in Experiment 1 the mean false recognition rate was much larger than that observed in Experiment 3 (0.58 vs. 0.38, respectively). The lower false recognition rate in Experiment 3 may be reflective of a stricter response criterion. That is, in Experiment 3 participants may have only endorsed lure items as "old" when memory was associated with a phenomenal sense of recollection. Thus, in Experiment 3, means-end problem solving may have been linked to both false recognition and recall because both forms of memory were supported by episodic processing (i.e., recollection). We note that this explanation for the disparity across experiments is post hoc. An important avenue for future research would be to isolate and quantify the contribution of recollection and familiarity-based responding during false recognition (e.g., with the remember-know task; Tulving, 1985). Based on the present findings, we would predict that estimates of recollection but not familiarity would be predictive of the steps generated in the MEPS task.

Links between episodic memory processing and the EDT

In Experiment 2, performance on the EDT was not significantly associated with false memory, in contrast to the MEPS task in Experiment 1. These results suggest that the constructive episodic memory processes that lead to false recall are uniquely related to problem solving as operationalized by the MEPS task and not the EDT. Although the previously discussed findings of Vandermorris et al. (2013) suggest that the EDT, akin to the MEPS task, may draw on episodic processes, there is some evidence that the EDT relies on *different* processes than those engaged by the MEPS task. For instance, Vandermorris et al. (2013) reported that only in the MEPS task was there evidence for a statistically significant age-related reduction in internal (i.e., episodic) detail production. In contrast, older adults produced a statistically equivalent amount of internal details as young adults on the EDT. The reverse was observed for external details: older adults produced a statistically equivalent number of external details as young adults on the MEPS task, but they produced significantly *more* external details on the EDT. These previous findings suggest that the EDT may not recruit episodic processing in the same way as the MEPS task, because performance on the task was not susceptible to age-related reductions in episodic processing. Moreover, in Vandermorris et al. (2013), the number of internal details generated in the MEPS task and EDT were collapsed into a single measure of problem-solving before they were correlated with the number of internal details on the Autobiographical Interview. It is possible that the positive correlation observed between problem solving and the Autobiographical Interview may have been driven by the MEPS task and not the EDT.

In conjunction with these prior findings, our results further suggest that the EDT does not require the same constructive episodic processes as the MEPS task, as false recall did not correlate with EDT performance. The MEPS task and EDT differ in that the problem scenarios in the MEPS task are not as frequently encountered relative to those in the EDT, and step generation in the MEPS task explicitly requires the prevention of a bad outcome. Both of these factors may bias participants to use simulation-related processes in the MEPS task that invoke greater retrieval and recombination demands relative to the EDT. It is this flexible recombination process that may also lead to increased false memory (and is also influenced by the Episodic Specificity Induction (ESI); e.g., Thakral et al., 2019). Future studies should systematically test the familiarity of the prompts in each task, as the novelty of a given scenario may vary from participant to participant. One possibility is that EDT performance may positively correlate to false memory, but only when a given EDT problem is relatively novel and not previously encountered, necessitating episodic retrieval and recombination.

In contrast to false memory, performance on the EDT was positively related to true recognition in Experiment 2. This significant relationship between true recognition and EDT performance is reminiscent of Thakral et al. (2021), where true recognition was positively related to convergent creative thinking (i.e., the ability to generate the single best solution to a problem) as operationalized in the Remote Associates Test (Mednick, 1962). In this task, participants generate the single solution word (e.g., bath) to link other word triads (e.g., room, blood, salts). One possible interpretation of the link between the EDT and true recognition is that the EDT may be approached similarly to the Remote Associates Test in that the steps generated to solve an EDT prompt may *converge* on a single best solution (e.g., the solution space for the EDT prompt "how would you organize a move to a new place?" may be relatively constrained by factual knowledge of such a scenario). This stands in contrast to both the AUT and MEPS task, where the generated content is not constrained by accuracy, and there is no single best/accurate solution. Thakral et al. (2021) attributed the link between true recognition and convergent thinking to common memorial decision processes such as source monitoring (Johnson, 2006). This decision process allows for the effective weighing of retrieved information in order to make an accurate/true memory response and an accurate response during convergent thinking. A similar process may be recruited when generating steps in the EDT. An additional possibility is that the Remote Associates Test and EDT may commonly rely on semantic processing. As noted above, relative to the MEPS task, the EDT employs problems/scenarios that people encounter more frequently, and therefore step generation in the EDT may draw on factual knowledge associated with the scenario. Similar to the EDT, it is known that performance on the Remote Associates Test involves semantic processing (e.g., the generation of semantic associates; Mednick, 1962). It will be important for future research to directly compare the Remote Associates Test and EDT, to assess the cognitive similarity across these two types of creative thinking and problem-solving.

In Experiment 3 we adopted a critical manipulation where the EDT was performed *after* the MEPS task. This manipulation allowed us to test the hypothesis that the MEPS task would bias participants to recruit a similar episodic problem-solving strategy when performing the EDT. This hypothesis was supported: in Experiment 3, steps generated on the EDT were positively correlated with false memory. Moreover, EDT performance was no longer significantly correlated with true recognition, in contrast to Experiment 2, but in line with results from Experiments 1 and 2 showing that performance in the MEPS task was not correlated with true memory. Although we must exercise caution interpreting null results, these convergent findings nonetheless provide evidence that our manipulation of task order was effective and that participants invoked the same task strategy in the EDT as in the MEPS task. In line with our interpretation of the MEPS findings from Experiments 1 and 3 above, participants may have engaged in a similar episodic event construction process when generating steps in the EDT in Experiment 3 (e.g., constructing and simulating the problem in order to generate steps). It is this episodic retrieval mechanism that also enhanced false memory generation in the DRM (for a further discussion, see Thakral et al., 2019).

Across experiments, the four cognitive tasks were administered in the same order (i.e., DRM-recall, DRM-recognition, AUT/MEPS (in Experiment 1), AUT/EDT (in Experiment 2), and MEPS/EDT (in Experiment 3). This raises the possibility that any correlation observed between false recognition and ensuing tasks (e.g., AUT) may have been attributable to the prior recall test. There are three main reasons why we argue that task order did not impact the results. First, in our prior study (Thakral et al., 2021), two experiments were conducted: one where recognition memory was tested alone and another where recall and then recognition memory was tested. In both experiments, quantitative divergent thinking was significantly and positively correlated with rates of false recognition (with the magnitude of these correlations not significantly differing and virtually identical; 0.51 vs. 0.49, $p > 0.20$; Preacher, 2002). In addition, overall rates of true, false, and distractor recognition were also almost identical across those experiments (e.g., rates of false recognition were 0.51 and 0.55). The fact that these findings replicated across experiments where the memory test procedure differed indicates that there was no appreciable impact on false recognition by the prior recall test. Importantly, these findings also demonstrate that the administration of a prior recall test is not necessary for false recognition to be positively correlated with divergent thinking. Based on these findings, we opted to implement the identical test procedure in the current study (i.e., recall followed by recognition).

Second in Experiment 1 of the current study, the positive correlation between false memory and MEPS performance was specific to false recall (r = 0.41) and did not extend to false recognition (r = 0.16). If recognition performance were dependent on prior recall, a significant correlation would have been observed between false recognition and MEPS performance, but this was again not the case. Lastly, performance in the EDT did not significantly correlate with either false recognition/recall (although the correlation between EDT performance and false recognition was statistically significant, it did not survive correction for multiple comparisons, nor was it a significant predictor in any of the regression analyses). This pattern directly contrasts with the AUT which was correlated with both types of false memory in both our prior study (Thakral et al., 2021) and in Experiments 1 and 2 of the current study. If task performance on the AUT influenced performance on the ensuing EDT, then performance in both tasks would have correlated with false memory. This was not case, and thus there was no evidence for the presence of a task order confound.

Our current conception of the cognitive link between false memory and divergent creative thinking/problem solving is one of a common constructive process, where bits and pieces of a past event (e.g., the who, what, when, and where) are combined at the time of retrieval, which leaves memory prone to distortion, but also allows for solutions to be generated to open-ended problems. An alternative account is the dual-retrieval model of recall (Brainerd et al., 2009; Brainerd et al., 2014), in which studied items are remembered via a pair of retrieval processes: direct access and reconstruction. Verbatim information is retrieved through direct access. When verbatim information cannot be accessed, retrieval occurs through a search process that is inherently error-prone, because search is guided by reconstructed and partially-identifying information (such as gist or non-item-specific information). With respect to true and false recall, direct access is assumed to support only true recall, whereas the reconstruction process supports false as well as true recall (Brainerd et al., 2009). Although the current data cannot distinguish between these views of constructive episodic processing, it will be important for future research to specify the specific processes that link episodic memory to problem solving and creative thinking (e.g., by independently manipulating the contribution of direct access versus the contribution of reconstruction to performance).

One limitation of the present study is that true and false memory was operationalized through strictly the DRM paradigm. Prior research has shown that DRM-based false memories do not relate to other forms of memory error, such as misinformation errors, imagination inflation, and autobiographical memory errors (e.g., Bernstein et al., 2018; Nichols & Loftus, 2019; Ost et al., 2013; Patihis et al., 2018; Zhu et al., 2013). These findings lend support to the idea that there are distinct episodic constructive processes that yield different memory errors (for a discussion see, Roediger, 1996; Schacter et al., in press). An open question is whether means-end problem-solving and divergent thinking are also supported by the same episodic constructive processes that lead to more complex memory errors such as autobiographical memory errors. This is a topic for future research.

To conclude, across three experiments we tested the idea that the same constructive episodic retrieval processes that contribute to adaptive functions like divergent creative thinking and problem solving, also leave memory prone to error and distortion. We presented two replications of the results from Thakral et al. (2021), demonstrating a direct link between false memory and quantitative divergent thinking. Critically, we also revealed for the first time a direct link between false recall and means-end problem solving. Our results suggest that this association extends to another form of problem solving as assessed in the EDT, but only when conditions encourage episodic processing. Together, these findings provide evidence for a direct link between the adaptive benefits of constructive episodic processes, in the form of enhanced divergent creative thinking and problem solving, and costs, in the form of increased memory error.

Open practices statement Data and materials are available upon direct request and are subject to anonymization to protect the privacy of participants. IRB permissions were not obtained to allow data to be uploaded to an online repository. As such, requestors must have approval from their IRB and acknowledge the source of the data in any reports using the data. Additionally, a Data Usage Agreement (DUA) is required before any data and/or materials will be made available. None of the experiments were preregistered.

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