Cognition 217 (2021) 104905

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/cognit

Original articles

Linking creativity and false memory: Common consequences of a flexible memory system

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ARTICLE INFO

Keywords:
Episodic memory
Divergent thinking
Convergent thinking
Recall
Recognition
Memory distortion

ABSTRACT

Episodic retrieval plays a functional-adaptive role in supporting divergent thinking, the ability to creatively combine different pieces of information. However, the same constructive memory process that provides a functional-adaptive benefit can also leave memory prone to error. In two experiments, we employed an individual differences approach to examine the relationship between different forms of creative thinking (divergent and convergent thinking) and false memory generation in the Deese-Roediger-McDermott paradigm. In Experiment 1, and replicating prior findings, false recognition was significantly predicted by convergent thinking performance. Critically, we also observed a novel predictive relationship between false recognition and quantitative metrics of divergent thinking performance. In Experiment 2, these findings were replicated and we further showed that false recall was predicted by quantitative metrics of divergent thinking. Our findings suggest that constructive memory processes link creative thinking with the production of memory errors.

Episodic memory depends on flexible constructive processes. These constructive processes are considered to be 'adaptive' because they have been shown to support other critical cognitive functions, such as episodic simulation (i.e., the ability to imagine novel and specific future episodes; for reviews, see Klein, 2013; Schacter, 2012; Schacter, Benoit, & Szpunar, 2017; Szpunar, 2010). The *constructive episodic simulation hypothesis* states that episodic simulation draws on the same neurocognitive processes that support episodic memory (i.e., the retrieval and flexible recombination of episodic details; Schacter & Addis, 2007, 2020). One line of evidence in support of this hypothesis comes from an episodic specificity induction, where participants remember past episodes and imagine future episodes in greater episodic detail after receiving brief training in recollecting specific past episodic details compared with various control inductions (Madore, Gaesser, & Schacter, 2014; Madore & Schacter, 2016; for a review, see Schacter & Madore, 2016).

A related set of studies have revealed a broader role for episodic retrieval in other adaptive cognitive functions that do not require episodic memory, but may still involve the retrieval and recombination of episodic detail. One such function is *divergent thinking*, or the ability to generate creative ideas by combining diverse types of information (Guilford, 1967). For example, after receiving the specificity induction, participants generate more novel uses for objects (e.g., using a rock as a paperweight) on the Alternate Uses Task (AUT) – a standard test of *divergent creative thinking* (Guilford, 1967) – than after receiving a control induction (Madore, Addis, & Schacter, 2015; Madore, Jing, & Schacter, 2016). Critically, the specificity induction did not influence performance on the Remote Associates Task (RAT) – a standard test of *convergent creative thinking* (Mednick, 1962) – where participants generate the single best solution word (e.g., *bath*) to link other word triads (e.g., *room, blood, salts;* Madore et al., 2015). Unless otherwise specified, from here on, the term 'divergent thinking task' refers to the use of the AUT, and 'convergent thinking task' refers to the use of the RAT.

Neuropsychological and neuroimaging studies also support a link between episodic memory, future thinking, and divergent thinking. For example, patients with memory impairments also exhibit deficits in divergent thinking (Duff, Kurczek, Rubin, Cohen, & Tranel, 2013). In addition, studies employing functional magnetic resonance imaging (fMRI) indicate that brain regions involved in episodic memory, such as the hippocampus, are also recruited during imagining and divergent thinking (Beaty, Thakral, Madore, Benedek, & Schacter, 2018; Benoit & Schacter, 2015; Thakral, Madore, & Schacter, 2017; for related evidence from fMRI studies employing the specificity induction, see Madore,

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https://doi.org/10.1016/j.cognition.2021.104905
Received 11 December 2020; Received in revised form 2 September 2021; Accepted 6 September 2021

Szpunar, Addis, & Schacter, 2016; Madore, Thakral, Beaty, Addis, & Schacter, 2019). More recently, a fMRI-guided transcranial magnetic stimulation (TMS) study showed that following TMS-induced disruption to the hippocampus, participants generated fewer episodic details when imagining a future episode and also generated fewer ideas on the divergent thinking task (Thakral, Madore, Kalinowski, & Schacter, 2020).

These prior studies support the general idea that the flexibility of episodic memory has an adaptive benefit. However, a critical tenet of the constructive episodic simulation hypothesis is that the same flexible episodic retrieval processes that provide adaptive benefits can also lead to memory errors (e.g., Schacter & Addis, 2007, 2020; Schacter, Carpenter, Devitt, & Thakral, 2021; Schacter, Guerin, & St. Jacques, 2011). We have found indirect evidence for this idea by assessing the production of memory errors in the Deese-Roediger-McDermott (DRM) paradigm (Deese, 1959; Roediger & McDermott, 1995), in which participants learn a list of semantically related words (e.g., *sweet, honey, candy*) that relate to a non-presented critical lure word (e.g., *sugar*). We found that in addition to the previously observed beneficial effects of a specificity induction on memory, simulation, and divergent thinking, the specificity induction also increased false recall of critical lure words in the DRM paradigm (Thakral, Madore, Devitt, & Schacter, 2019). Recent work has also found direct links between the adaptive benefits of flexible episodic processing and memory errors. For example, Dewhurst, Anderson, Grace, and van Esch (2016) investigated the effect of episodic simulation on false memory. They found that participants exhibited higher levels of false recall and recognition of critical lure words in the DRM paradigm after thinking about how the studied words might be used in a future situation that required planning, compared to rating the encoded words according to pleasantness or encoding the words in reference to a past event. Similarly, Carpenter and Schacter (2017, 2018) reported a link between flexible recombination processes that support adaptive associative inference and memory errors that result from mistakenly combining elements of distinct but related episodes.

1. The current study

The prior findings show that a flexible episodic memory system has functional benefits for creativity (among other processes), but also has costs in that this system contributes to memory distortion. If the same flexible memory system is responsible for both of these positive and negative consequences, then there should be a *direct* link between creativity and susceptibility to memory distortion (for a general discussion of the relation between creativity and memory errors, see Ditta & Storm, 2018). However, previous studies examining such a link have yielded inconclusive results. For example, Hyman and James Billings (1998) found that creativity (as measured by the Creative Imagination Scale) is positively related to the incidence of false childhood memories (Hyman & James Billings, 1998), and people who report memories from a past life score higher on a divergent thinking task than those who do not (Meyersburg, Carson, Mathis, & McNally, 2014). Meyersburg, Bogdan, Gallo, and McNally (2009) found that participants who reported past life memories also generate more DRM-based false memories. In contrast, some studies employing the Creative Experiences Scale (Merckelbach, Horselenberg, & Muris, 2001), which measures how fantasy prone people are, have failed to find a link with DRM-based false memory (Bernstein, Scoboria, Desjarlais, & Soucie, 2018; Nichols & Loftus, 2019; Patihis, Frenda, & Loftus, 2018).

Directly relevant to our prior specificity induction work, Dewhurst, Thorley, Hammond, and Ormerod (2011) found that increased susceptibility to DRM-based false recognition is associated with better convergent thinking performance, but not divergent thinking performance. Dewhurst et al. (2011) reasoned that the association between false recognition and convergent thinking reflects a common reliance on the generation of semantic associations. In contrast, divergent thinking requires the generation of novel ideas and therefore has less overlap with the processes that underlie false recognition in the DRM. Yet these findings appear to be inconsistent with our experiments showing that the specificity induction enhances divergent, but not convergent, thinking (Madore et al., 2015; Madore et al., 2019; Madore et al., 2016), and also boosts false recall in the DRM paradigm (Thakral et al., 2019). This seeming inconsistency may reflect the fact that in Thakral et al. (2019) we measured false recall instead of false recognition. Additionally, we scored the divergent thinking task as a function of both the *quantity* (e.g., number of uses generated, or fluency) and *quality* (e.g., ratings of creativity or originality) of uses (Madore et al., 2015, Madore et al., 2019, Madore et al., 2016). The specificity induction effect was present for quantitative but not qualitative metrics of divergent thinking performance. In contrast, Dewhurst et al. (2011) only scored the quality of uses generated.

The goal of the present study was to identify a direct link between the underlying flexible episodic processes that contribute to creative thinking and to susceptibility to false memory. To help achieve our goal, we attempted to address the foregoing inconsistences by employing the procedures of Dewhurst et al. (2011). Our first aim was to replicate the relationship between convergent thinking and DRM-based false recognition. Our second aim was to test novel hypotheses regarding shared memory-related processes across DRM-based false recall and recognition and different metrics of creativity; we expand on these hypotheses below. Note that from here on, we use the term 'quantitative divergent thinking' which is equivalent to 'generative divergent thinking' (cf., Madore et al., 2019).

2. Hypotheses

Why should false recognition and recall be linked to creative thinking? According to the constructive memory framework (Schacter, Norman, & Koutstaal, 1998), false recognition and false recall arise as a result of different mechanisms. False recall is attributed to failures in *pattern completion:* the reactivation of a partially overlapping set of features associated with an encoded event spreads to the rest of the features of that event. As recall is itself a pattern completion process, inaccuracies in recall result from the construction of a retrieval cue that is inconsistent with the intended memory. Thus, the reliance on gist-based retrieval cues may result in false recall in the DRM paradigm. Akin to the link between recall and cue generation, researchers have argued that divergent thinking involves greater self-generated thought than convergent thinking (e.g., Benedek et al., 2016; Christoff, 2013). We have argued that it is this idea generation during quantitative divergent thinking that is impacted by the specificity induction and is therefore attributable, at least in part, to the retrieval and recombination of specific episodic details (e.g., Madore et al., 2019; Schacter & Madore, 2016). Moreover, free recall relies primarily on recollection-based episodic memory processes (Mandler, 1980; Yonelinas, 2002; Yonelinas, Aly, Wang, & Koen, 2010). In line with this general idea, the specificity induction, which impacts primarily episodic processes, boosts both false recall and quantitative metrics of divergent thinking but not convergent thinking (e.g., Madore et al., 2015; Thakral et al., 2019). As such, we hypothesized that false recall would be correlated with quantitative divergent thinking, with this relationship likely reflecting a common reliance on shared pattern completion and episodic/recollection-related processing.

The constructive memory framework states that false recognition arises from a failure of *pattern separation* during encoding whereby studying semantically related words results in high levels of overlap between item representations, which leads to memory for what the items have in common (i.e., gist information). By relying on the gist information, studied words and critical lures fail to be discriminated. In addition to a failure in pattern separation, Schacter et al. (1998) argued that false recognition can also result from 'implicit associative responses'; the overt or covert generation of a lure word during the encoding of associated word lists. Akin to recognition, and in contrast to both divergent thinking and recall, convergent thinking is more directly constrained by the properties of the presented words (e.g., triads in the convergent thinking task and recognition memory cues, respectively). Convergent thinking therefore does not require the level of self-generated episodic information as in quantitative divergent thinking and false recall, relying to a greater extent on the generation of associative information to a given stimulus (Mednick, 1962). As reasoned by Dewhurst et al. (2011), the positive correlation between false recognition and convergent creative thinking reflects the ability to generate broad semantic associations to a given stimulus (see also, Roediger, Watson, Mcdermott, & Gallo, 2001). Additionally, recognition memory is thought to rely on both recollection and familiarity-based recognition (Mandler, 1980; Yonelinas, 2002); the latter is commonly associated with semantic memory (e.g., Slotnick, 2017; Wagner & Gabrieli, 1998; Wang, Ranganath, & Yonelinas, 2014; Wang & Yonelinas, 2012). Because both convergent thinking and quantitative divergent thinking have been shown to be supported by semantic processing (e.g., Abraham et al., 2012; Beaty et al., 2020; Hass, 2017; Marko, Michalko, & Riecansky, 2019; Shen et al., 2016), we predicted that both forms of creativity would be related to false recognition.

In summary, across two experiments we employed an individual differences approach to replicate the results of Dewhurst et al. (2011), and test novel predictions regarding the relationship between false recognition and recall in the DRM paradigm, and different metrics of creative performance. In Experiment 1, we examined the relationship between false recognition, convergent thinking (as measured in the RAT), and qualitative and quantitative metrics of divergent thinking (as measured in the AUT). We hypothesized that higher convergent thinking performance would be associated with higher false recognition rates, with no relationship between qualitative divergent thinking and false recognition, consistent with the results of Dewhurst et al. (2011). As a novel extension of these findings, we hypothesized that higher quantitative divergent thinking would also be associated with higher false recognition. In Experiment 2, we attempted to replicate the findings from Experiment 1, and further examined the relationship between false recall and convergent and divergent thinking. We predicted that higher false recall rates would be associated with higher quantitative divergent thinking performance.

3. Experiment 1

3.1. Material and methods

3.1.1. Participants

The experimental protocol was approved by the Institutional Review Board of Harvard University and informed consent was obtained prior to participation. Fifty-nine Amazon Mechanical Turk workers participated for compensation ($4.50). All workers were located in the United States, had a HIT (human intelligence task) approval rate greater than 95%, and had greater than 50 HITs approved. Four participants were excluded for noncompliance (2 self-reported cheating, 1 did not follow instructions for the AUT, and 1 did not complete the RAT), and three additional participants were excluded for performing greater than 2 standard deviations above the mean performance on the RAT. Notably, our key findings replicate when we include the high performers. The analyzed sample size of 52 (mean $\pm$ (1 standard error) age of 24.5 $\pm$ 0.32, range of 18–30, 34 females (1 person identified as transgender male)) is virtually identical to the study of Dewhurst et al. (2011), which employed a sample size of 55[1]. A post-hoc power analysis using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) conducted using the correlations identified in the present study revealed that a sample of 52 participants is sufficient for detecting at least a medium-sized effect ($r = 0.59$; power > 0.80, two-tailed correlation between false recognition and convergent thinking; similar results were obtained using the effect sizes reported in Dewhurst et al., 2011).

3.1.2. Stimuli and task

In a single session, participants completed the following tasks in this order: (a) DRM word list encoding, (b) a distractor task, (c) a recognition memory test for the DRM lists, (d) the divergent thinking task (AUT), and (e) the convergent thinking task (RAT). We adapted the experimental paradigm of Dewhurst et al. (2011) for online data collection.

3.1.2.1. Encoding. Participants were visually presented 8 DRM lists with 12 words each (96 words total), and were instructed to encode the words for a later memory test. Each word was presented for 2 s, with a 1 s intertrial interval. Words within each list were presented from highest to lowest backward associative strength. Two sets of 8 DRM lists were used in the study. One set comprised words corresponding to the following critical lures: *slow, needle, sleep, sweet, mountain, car, anger,* and *smell*. The other set comprised words corresponding to the following critical lures: *city, chair, pen, foot, smoke, window, trash,* and *spider*. The two sets of lists were statistically equated for the probability of eliciting false recognition and recall (ps $>$ 0.20; Stadler, Roediger, & McDermott, 1999). In a counterbalanced design, one set was used as studied words and the other set was used as new words an equal number of times across participants with list assignment randomized across participants. We chose 8 DRM lists to replicate the procedures of Dewhurst et al. (2011). In addition, using 8 or fewer DRM lists has been shown to produce reliable individual differences in false memory (Blair, Lenton, & Hastie, 2002).

3.1.2.2. Distractor task. Participants had 1 min to complete the single-letter cancellation task (SLCT; Diller et al., 1974; Deng et al., 2019). In this task, participants were shown a 12 $\times$ 13 array of single letters and were asked to select all the instances of the letter B which were placed 52 times randomly in the array.

3.1.2.3. Recognition. Participants were given a recognition memory test for the studied words, in which an 8 $\times$ 4 array of studied words, critical lure words, non-studied words, and non-studied critical lure words were shown. The allocation of word type to array position was randomized. Of the 32 words, 1 word was randomly selected from each of the 8 studied lists (i.e., 8 studied words), 8 critical lures from each of the studied lists, 1 word was randomly selected from each of the 8 non-studied lists (i.e., 8 non-studied/new words), and 8 non-studied/critical lures from each non-studied list. Participants were instructed to read each word carefully and select only those words they thought were presented on any of the lists they previously saw. The test phase was self-paced. Note that this procedure is a departure from more standard old/new recognition tests where test items are shown sequentially. As we detail below, rates of true and false recognition replicate prior studies (e.g., Dewhurst et al., 2011), as well as prior studies employing a sequential presentation of test items (for a review, see Gallo, 2010), and thus differences in recognition test methodology are not of concern.

3.1.2.4. Divergent thinking task (AUT). To assess creativity, we used the AUT and RAT because they are commonly employed, reliable, and valid tasks used to isolate divergent and convergent thinking (see Carson, Peterson, & Higgins, 2005; Lee, Huggins, & Therriault, 2014; Plucker, 1999; Runco, Millar, Acar, & Cramond, 2010; Wu, Huang, Chen, & Chen, 2020). In the divergent thinking task, participants were shown a single object word (‘brick’) and were instructed to type as many possible uses for the object on the screen. Participants were given an example object word (e.g., ‘notebook’), and two possible answers (e.g., using the

[1] Our sample size of 52 was chosen to be highly similar to the study of Dewhurst et al. (2011) which served as the basis of the present study, which employed an N of 55. As we note in the Results, we replicated the results from the reported by Dewhurst et al. (2011). In addition, we recently conducted an additional follow-up experiment that employed highly similar experimental procedures as the submitted study (i.e., participants completed the DRM paradigm followed by the AUT). In this experiment, we collected an N of 52 and critically, we replicated the current findings. These consistent and significant observations demonstrate the reproducibility of the primary effects.

paper of the notebook as kindling for a fire or using the notebook to swat a fly). The object word was shown for 8 min during which time participants were instructed to keep generating and typing out uses. Participants were given 20 empty slots to type their generated uses.

3.1.2.5. Convergent thinking task (RAT). In the convergent thinking task, participants saw 24 triads, each consisting of three words, and were asked to generate a solution word that could be combined with each word in the triad to form a common compound word or phrase. Participants were shown one example triad and solution: "EIGHT/SKATE/STICK" the solution word would be "Figure." The solution word Figure forms the word pairs "FIGURE EIGHT", "FIGURE SKATE", and "STICK FIGURE". The 24 triads were randomly selected as a subset of the 30 triads employed in Madore et al. (2015; see also, Bowden & Jung-Beeman, 2003) that between 0% and 46% of individuals could solve in 30 s. The 24 triads were shown for 8 min during which time participants were instructed to keep generating and typing words that relate to the triads shown.

Following completion of the convergent thinking task, participants completed a demographic questionnaire and were probed for possible cheating via two questions. The first question asked participants if they wrote down any of the words during the encoding phase to facilitate memory, and the second question asked participants if 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 (2 participants total, see above).

The methods described above follow experimental procedures recommended in prior studies employing the AUT (e.g., Benedek, Mühlmann, Jauk, & Neubauer, 2013; Silvia et al., 2008) indicating that using a single cue word with a task time of 3 min provides reliable divergent thinking scores (e.g., fluency and originality scores show high reliability ($\alpha > 0.85$) for a time-on-task of 3 min when comparing performance across different test items in the AUT; Benedek et al., 2013). With respect to convergent thinking, a recent meta-analysis demonstrated that the RAT as employed in the current study is the most commonly employed task to isolate convergent thinking (Wu et al., 2020).

3.1.3. Scoring and analysis

Convergent thinking responses were scored as the summed number of correct responses across all trials for each participant (e.g., Madore et al., 2015). The divergent thinking task was scored as a function of the *quality* of uses generated, as in Dewhurst et al. (2011), and the *quantity* (Guilford, Christensen, Merrifield, & Wilson, 1960; Guilford, 1967; Benedek, Jauk, Fink, Koschutnig, Reishofer, Ebner, & Neubauer, 2014; Madore et al., 2015, 2019; Addis, Pan, Musicaro, & Schacter, 2016). A single qualitative measure was computed as *originality* (i.e., a rating of the perceived novelty and appropriateness of each use, ranging from 1 (uncreative) to 4 (very creative), with scores of 3 and 4 given to only a few uses per participant). Quantitative measures included *fluency* (i.e., total uses generated excluding repetitions), *flexibility* (i.e., the number of distinct categories that appropriate uses could be classified under), *appropriateness* (appropriate uses received a score of 1 and inappropriate uses a score of 0), and *elaboration* (i.e., a rating of the level of detail associated ranging from 0 to 2). The fluency, flexibility, appropriateness, and elaboration measures reflect 'quantity' of divergent thinking as each quantifies the amount of detail generated in different ways (e.g., the elaboration rating measures the amount of detail generated within a given response, and the fluency score reflects the total number of ideas generated). This stands in contrast to the originality rating which measures the 'quality' of the response (i.e., uniqueness) ignoring the amount generated. As noted in the Introduction, Dewhurst et al. (2011) focused only on qualitative metrics of divergent thinking (i.e. originality), and did not find a link with false recognition. Thus, one our aims was to assess whether a linkage to false recognition and divergent thinking would be found if one examined quantitative metrics of divergent thinking. Treating quantitative and qualitative metrics as separate entities follows a large number of our own and other studies (e.g., Silvia et al., 2008; Benedek et al., 2013, 2014; Madore, Szpunar, et al., 2016; Madore et al., 2019). Our own prior work has indicated that the contribution of episodic processing on divergent thinking is unique to quantitative metrics of divergent thinking (e.g., Madore et al., 2019; Madore et al., 2016). Therefore, given our aim in linking episodic construction-related processes to divergent thinking, it was important to isolate generative/quantitative divergent thinking.

For each divergent thinking measure, the scores were averaged across trials to create a standardized measure of performance. As in our prior work (e.g., Addis et al., 2016) and to reduce multiple comparisons, these four quantitative metrics were mean-centered and collapsed into a mean quantitative divergent thinking score for use in the regression analyses (the quantitative metrics were highly inter-correlated with r values ranging from 0.43 to 0.99). One rater scored all responses, we confirmed inter-rater reliability of these divergent thinking measures with a separate second rater and obtained high reliability (Cronbach's $\alpha = 0.90$).

Following the analysis methods of Dewhurst et al. (2011), hierarchical multiple regression analyses were used to assess the ability of convergent thinking and divergent thinking to predict rates of false recognition (i.e., rates of selecting a critical lure word during the recognition test) and true recognition (i.e., rates of selecting a studied word during the recognition test). We confirmed that there were no violations of the assumptions of normality, linearity, multicollinearity (variance inflation factor < 5), and homoscedasticity. Our first regression analysis was conducted to replicate the results of Dewhurst et al. (2011) and assess whether convergent thinking (operationalized as accuracy in the convergent thinking task) would predict false recognition, with no or a weaker relationship with qualitative divergent thinking (operationalized as originality in the divergent thinking task) and false recognition (Dewhurst et al., 2011). As a novel extension of Dewhurst et al. (2011), we went on to assess whether quantitative divergent thinking (i.e., the mean-centered divergent thinking quantitative score across fluency, flexibility, appropriateness, and elaboration) predicted false recognition. An analogous set of analyses were run to assess whether convergent and both qualitative and quantitative divergent thinking predicted true recognition. All results are considered significant at the $p < 0.05$ level.

3.2. Results

Complete recognition data from Experiment 1 are listed in Table 1. Overall rates of true, false, and distractor recognition are similar to those reported in Dewhurst et al. (2011). These findings demonstrate the validity of the online data collection method and provide evidence that false memories can be generated in an online version of the DRM paradigm. We assessed internal reliability of false recognition rates using Cronbach's α (Cronbach, 1951; Falk & Savalei, 2011), which was acceptable ($\alpha = 0.73$), indicating that the tendency to falsely recognize a lure was stable within the experiment. Complete creativity data for the divergent and convergent thinking tasks from Experiment 1 are listed in Table 2. Accuracy in the convergent thinking task and originality in the divergent thinking task are also similar to those reported in Dewhurst et al. (2011)[2] as well as other studies (e.g., Silvia et al., 2008; Benedek

[2] The originality scores for the AUT deviate from those reported in Dewhurst et al. (2011), who reported originality as 26.91. Dewhurst et al. (2011) computed their originality score as the sum originality for each trial without taking an average. When computing the originality score in an identical fashion, the current originality score was almost identical (26.31). We opted to compute our originality score to be consistent with our prior AUT data (Addis et al., 2016; Madore et al., 2015, Madore et al., 2016, Madore et al., 2019). Regardless, the results of all analyses were similar when adopting either originality metric, and thus the conclusions drawn from the present data do not change.

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 for each experiment.

	True recognition	False recognition	Distractor recognition	True recall	False recall
Experiment 1	0.58 (0.03)	0.51 (0.04)	0.09 (0.02)	–	–
Experiment 2	0.64 (0.03)	0.55 (0.04)	0.08 (0.02)	0.22 (0.02)	0.12 (0.02)

Table 2
Mean score (± 1 standard error of the mean) for each creativity task (AUT and RAT) and for each experiment.

AUT Score (Divergent thinking)	Experiment 1	Experiment 2
Quantitative metrics		
Fluency (total uses)	13.85 (0.75)	11.43 (0.65)
Flexibility (categories of appropriate uses)	7.00 (0.40)	5.40 (0.30)
Appropriateness (total appropriate uses)	13.79 (0.74)	11.38 (0.65)
Elaboration (0–2; higher = more detailed)	0.40 (0.05)	0.67 (0.06)
Qualitative metric		
Originality (1–4, higher = more original and infrequent)	1.84 (0.06)	1.59 (0.06)
RAT Score (Convergent thinking)		
Accuracy (total correct out of 24)	4.63 (0.50)	5.48 (0.65)

et al., 2014). Reliability in the convergent thinking task was also high ($\alpha = 0.79$), consistent with prior work (Lee et al., 2014).

3.2.1. *False recognition*

Bivariate correlations between all variables of Experiment 1 are listed in Table 3. Initial correlation analyses (Fig. 1, top and middle) revealed a significant relationship between false recognition and convergent thinking. The correlation between false recognition and qualitative divergent thinking did not survive correction for multiple comparisons. The regression analysis (see Table 4) revealed that convergent thinking accounted for 34.6% of the variance in false recognition ($F(1, 50) = 26.49$, $p = 4 \times 10^{-6}$). The addition of the qualitative divergent thinking scores in Step 2 resulted in a non-significant 4.30% increase in the explained variance ($\Delta F(1, 49) = 3.46$, $p = 0.07$). Therefore, replicating Dewhurst et al. (2011), and consistent with the correlations, we found that convergent thinking was a significant predictor of false recognition ($\beta = 0.55$, $t(51) = 4.89$, $p = 1.10 \times 10^{-5}$) whereas qualitative divergent thinking was not ($\beta = 0.21$, $t(51) = 1.86$, $p = 0.07$).

We then assessed whether quantitative divergent thinking was related to false recognition. Initial correlation analyses (Fig. 1, bottom) revealed a significant relationship between quantitative divergent thinking and false recognition[3]. When quantitative divergent thinking scores replaced the qualitative divergent thinking scores in Step 2 (see Table 5), there was a significant 6.00% increase in the explained variance ($\Delta F(1, 49) = 4.92$, $p = 0.03$). These findings suggest that both convergent thinking ($\beta = 0.46$, $t(51) = 3.72$, $p = 5.18 \times 10^{-4}$) and quantitative divergent thinking are significant predictors of false recognition ($\beta = 0.28$, $t(51) = 2.22$, $p = 0.03$).

To provide a full picture of the relationship between false recognition and creativity performance metrics, we ran a three-step hierarchical regression model with the convergent thinking scores entered at Step 1, the qualitative divergent thinking scores at Step 2, and quantitative divergent thinking scores at Step 3 (see Table 6). This analysis revealed that only convergent thinking was a significant predictor of false recognition ($\beta = 0.47$, $t(51) = 3.76$, $p = 4.57 \times 10^{-4}$), whereas qualitative and quantitative divergent thinking were not ($\beta s < 0.22$, $ts(51) = 1.60$, $ps > 0.12$).

[3] Replicating the original collapsed quantitative divergent thinking metric, each of the individual quantitative metrics (fluency, flexibility, elaboration, and appropriateness) were correlated with false recognition.

3.2.2. *True recognition*

While not the primary focus of this investigation, we also conducted an additional analysis to examine the predictive relationships between convergent thinking and divergent thinking with respect to true recognition. Based on the null relationships reported by Dewhurst et al. (2011) between true recognition and both convergent and qualitative divergent thinking, we opted to conduct a simultaneous multiple regression including all three predictors (see Table 7). Initial correlation analyses revealed that true recognition was related to convergent thinking, with the relationship to quantitative divergent thinking not surviving a correction for multiple comparisons, and the relationship to qualitative divergent thinking not significant. Convergent thinking and divergent thinking (qualitative and quantitative metrics) together accounted for 23.1% of the variance in true recognition ($F(3, 48) = 4.82$, $p = 5.17 \times 10^{-3}$). However, and paralleling the correlations, true recognition was only predicted by convergent thinking ($\beta = 0.36$, $t(51) = 2.52$, $p = 0.02$); neither qualitative or quantitative divergent thinking were significant predictors of true recognition ($\beta s < 0.22$, $ts(51) = 1.42$, $ps > 0.16$).

3.3. *Discussion*

The results of the regression analyses from Experiment 1 replicate those of Dewhurst et al. (2011), indicating that convergent thinking predicts false recognition while *qualitative* divergent thinking does not. These findings parallel the correlation analyses as the correlation between false recognition and qualitative divergent thinking did not survive a correction for multiple comparisons, while the correlation between false recognition and convergent thinking did. In addition, we found a novel relationship between *quantitative* divergent thinking and false recognition (however this relationship was not significant when both measures of divergent thinking were entered into the regression). As for true recognition, we did not replicate the null findings of Dewhurst et al. (2011). Instead, we found that true recognition is predicted by convergent thinking, with no relationship between true recognition and either metric of divergent thinking. These findings parallel the correlations, as only the correlation between true recognition and convergent thinking survived a correction for multiple comparisons. Taken together, the findings from Experiment 1 indicate that both true and false recognition are linked to convergent thinking, with false recognition also linked to quantitative divergent thinking.

In Experiment 2 we first aimed to replicate the findings of Experiment 1, in particular the novel findings of a relationship between a)

Table 3
Bivariate correlations between recognition, convergent thinking, and divergent thinking in Experiment 1 (*$p < 0.05$, **$p < 0.01$, ***$p < 0.005$; those that are $p < 0.005$ are also those that survive a Bonferroni correction for multiple comparisons).

	False recognition	True recognition	Convergent thinking	Qualitative divergent thinking	Quantitative divergent thinking
False recognition	1.00	0.39***	0.59***	0.30*	0.49***
True recognition		1.00	0.45***	0.07	0.35*
Convergent thinking			1.00	0.17	0.46***
Qualitative divergent thinking				1.00	0.43***
Quantitative divergent thinking					1.00

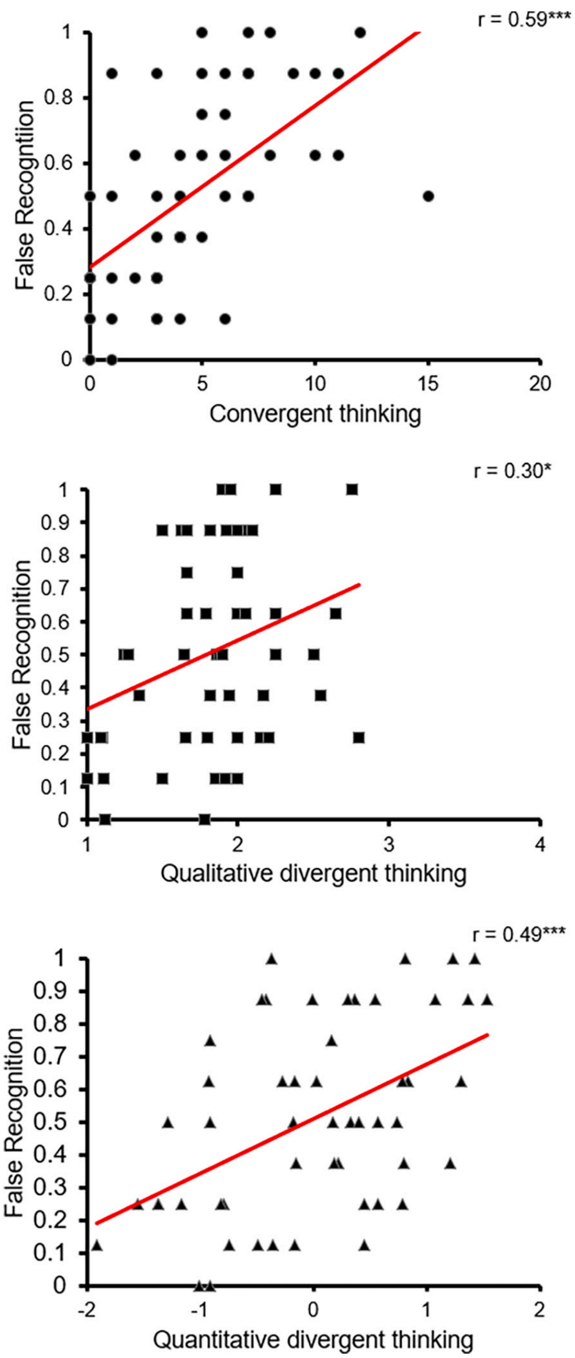

Fig. 1. Experiment 1 scatter plots and regression lines showing the correlations between false recognition and convergent thinking (top), qualitative divergent thinking (middle), and quantitative divergent thinking (bottom; *$p < 0.05$, **$p < 0.01$, ***$p < 0.005$; those that are $p < 0.005$ are also those that survive a Bonferroni correction for multiple comparisons).

Table 4
Summary of the hierarchical multiple regression analysis for convergent and qualitative divergent thinking in relation to false recognition (*$p < 0.05$).

Step	B	SE B	β
1			
Constant	0.28	0.06	
Convergent thinking	0.05	0.01	0.59*
2			
Constant	0.03	0.15	
Convergent thinking	0.05	0.01	0.55*
Qualitative divergent thinking	0.15	0.08	0.21

Table 5
Summary of the hierarchical multiple regression analysis for convergent and quantitative divergent thinking in relation to false recognition (*$p < 0.05$).

Step	B	SE B	β
1			
Constant	0.28	0.06	
Convergent thinking	0.05	0.01	0.59*
2			
Constant	0.33	0.06	
Convergent thinking	0.04	0.01	0.46*
Quantitative divergent thinking	0.10	0.04	0.28*

Table 6
Summary of the hierarchical multiple regression analysis for convergent, qualitative divergent thinking, and quantitative divergent thinking in relation to false recognition (*$p < 0.05$).

Step	B	SE B	β
1			
Constant	0.28	0.06	
Convergent thinking	0.05	0.01	0.59*
2			
Constant	0.03	0.15	
Convergent thinking	0.05	0.01	0.55*
Qualitative divergent thinking	0.15	0.08	0.21
3			
Constant	0.16	0.17	
Convergent thinking	0.04	0.01	0.47*
Qualitative divergent thinking	0.09	0.08	0.13
Quantitative divergent thinking	0.07	0.05	0.22

Table 7
Summary of the simultaneous multiple regression analysis for convergent, qualitative divergent thinking, and quantitative divergent thinking in relation to true recognition (*$p < 0.05$).

Step	B	SE B	β
1			
Constant	0.56	0.14	
Convergent thinking	0.02	0.01	0.36*
Qualitative divergent thinking	−0.04	0.07	−0.09
Quantitative divergent thinking	0.06	0.04	0.22

Table 8
Bivariate correlations between recognition, covergent thinking, and divergent thinking in Experiment 2 (*$p < 0.05$, **$p < 0.01$, ***$p < 0.005$; those that are $p < 0.005$ are also those that survive a Bonferroni correction for multiple comparisons).

	False recognition	True recognition	Convergent thinking	Qualitative divergent thinking	Quantitative divergent thinking
False recognition	1.00	0.39***	0.28*	0.17	0.51***
True recognition		1.00	0.36**	−0.07	0.27
Convergent thinking			1.00	0.17	0.38***
Qualitative divergent thinking				1.00	0.44***
Quantitative divergent thinking					1.00

Table 9
Bivariate correlations between recall, convergent thinking, and divergent thinking in Experiment 2 (*$p < 0.05$, **$p < 0.01$, ***$p < 0.005$; those that are $p < 0.005$ are also those that survive a Bonferroni correction for multiple comparisons).

	False recall	True recall	Convergent thinking	Qualitative divergent thinking	Quantitative divergent thinking
False recall	1.00	−0.14	0.13	0.19	0.37**
True recall		1.00	0.36**	0.05	0.01
Convergent thinking			1.00	0.17	0.38***
Qualitative divergent thinking				1.00	0.44***
Quantitative divergent thinking					1.00

quantitative divergent thinking and false recognition, and b) convergent thinking and true recognition. Our second aim was to assess whether the relationship between convergent thinking and true and false memory is specific to recognition-based memory, or whether this relationship extends to true and/or false recall. As we noted in the Introduction, recall is thought to be a more "process-pure" measure of recollection-based memory, and therefore may provide a more sensitive assessment of the commonality between episodic memory-related processing and creativity.

4. Experiment 2

4.1. Material and methods

4.1.1. Participants

The experimental protocol was approved by the Institutional Review Board of Harvard University and informed consent was obtained prior to participation. Fifty-nine Amazon Mechanical Turk workers participated for compensation ($4.50). All workers were located in the United States, had a HIT (human intelligence task) approval rate greater than 95%, and had greater than 50 HITs approved. We excluded four participants for noncompliance (1 self-reported cheating, 2 did not follow instructions for the AUT, and 1 did not complete the RAT), leaving $n = 55$. As in Experiment 1, 3 participants were excluded because they performed greater than 2 standard deviations above the mean performance on the RAT. As in Experiment 1, our key findings replicate when we include the high performers. The analyzed sample size of 52 is identical to Experiment 1 (sample (mean ± (1 standard error) age of 24.6 ± 0.27, range of 21–28, 24 females (1 person reported to be non-binary, 1 chose not to respond)).

4.1.2. Stimuli and task

The experimental procedure was similar to Experiment 1, with the exception that a single recall memory test was given after the distractor task and viewing all 8 DRM lists. Specifically, participants were given a blank text box and were instructed to type as many of the words as they could remember from the prior list presentation. There were told to be 'reasonably sure' that any word they typed was part of the lists they were shown. The usage of a single recall task (as opposed to a recall test following each presentation of a DRM list) follows procedures employed in other studies also using a recall-based version of the DRM (e.g., Bui, Friedman, McDonough, & Castel, 2013; McCabe & Smith, 2006; Thakral et al., 2019). The recall memory test was self-paced. Following the recall test, a recognition test was employed as in Experiment 1.

4.2. Results

Complete recognition data from Experiment 2 are listed in Table 1. Overall rates of true, false, and distractor recognition are similar to those observed in Experiment 1. Complete recall data are also listed in Table 1. Rates of true and false recall were both significantly greater than 0 (ts (52) > 6.31, ps < 0.001), indicating that an online recall version of the DRM can produce reliable false recall (for other examples, see Bui et al., 2013 who report similar rates of false recall). In addition, rates of intrusions were low with an average number of intrusions recalled 1.38 ± 0.27 confirming recall task compliance. As in Experiment 1, internal reliability of false recognition was acceptable (α = 0.77). Although the reliability of false recall (α = 0.48) did not approach the same 'acceptable' level (i.e., α > 0.70), the primary findings have been replicated[4]. Complete creativity data for the divergent and convergent thinking tasks from Experiment 2 are listed in Table 2 and are consistent with the data from Experiment 1. As in Experiment 1, reliability in the convergent thinking task was high (α = 0.86).

4.2.1. False recognition

Bivariate correlations between all variables of Experiment 2 are listed in Table 8 (recognition data) and Table 9 (recall data). Replicating Experiment 1, false recognition correlated with convergent thinking (Fig. 2A, top). False recognition was not significantly correlated with qualitative divergent thinking (Fig. 2A, middle). The regression analysis (see Table 10) revealed that convergent thinking accounted for 7.9% of the variance in false recognition ($F(1, 50) = 4.30$, $p = 0.04$). The addition of the qualitative divergent thinking scores in Step 2 resulted in a non-significant 1.50% increase in the explained variance ($\Delta F(1, 49) < 1$). As in Experiment 1, qualitative divergent thinking was not a significant predictor of false recognition ($\beta = 0.12$, $t(51) < 1$), and the beta coefficient for convergent thinking approached significance ($\beta = 0.26$, $t(51) = 1.89$, $p = 0.07$).

Turning to the relationship between false recognition and quantitative divergent thinking, the correlation between these variables was significant (Fig. 2A, bottom)[5]. When quantitative divergent thinking scores replaced the qualitative divergent thinking scores in Step 2 of the

[4] See Footnote 1.

[5] As in Experiment 1, replicating the original collapsed quantitative divergent thinking metric, each of the individual quantitative metrics (fluency, flexibility, elaboration, and appropriateness) were correlated with false recall and recognition.

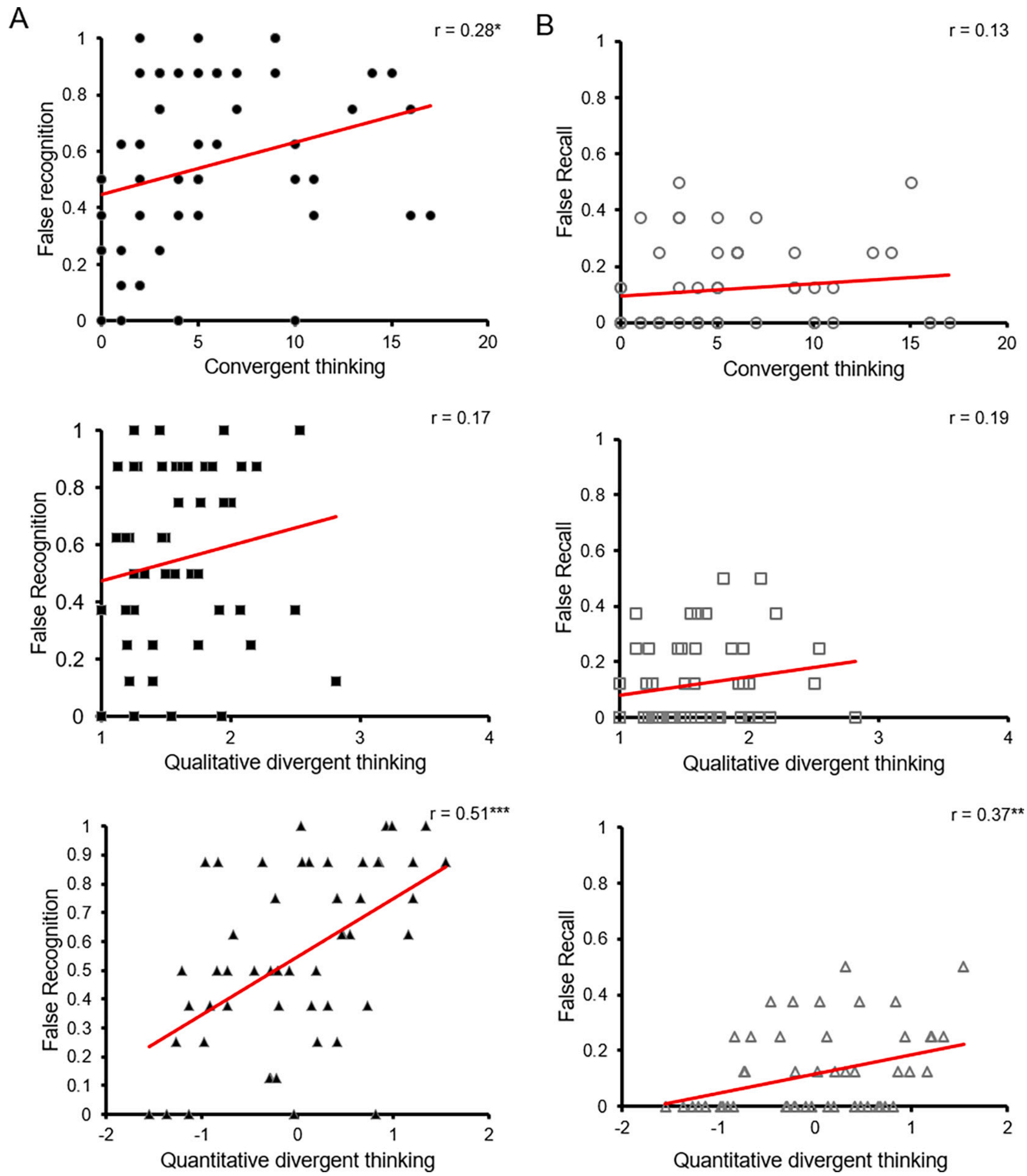

Fig. 2. A. Experiment 2 scatter plots and regression lines showing the correlations between false recognition and convergent thinking (top), qualitative divergent thinking (middle), and quantitative divergent thinking (bottom). B. Experiment 2 scatter plots and regression lines showing the correlations between false recall and convergent thinking (top), qualitative divergent thinking (middle), and quantitative divergent thinking (**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 10
Summary of the hierarchical multiple regression analysis for convergent and qualitative divergent thinking in relation to false recognition (*$p < 0.05$).

Step	B	SE B	β
1			
Constant	0.45	0.06	
Convergent thinking	0.02	0.01	0.28*
2			
Constant	0.31	0.17	
Convergent thinking	0.02	0.01	0.26
Qualitative divergent thinking	0.09	0.10	0.12

Table 11
Summary of the hierarchical multiple regression analysis for convergent and quantitative divergent thinking in relation to false recognition (*$p < 0.05$).

Step	B	SE B	β
1			
Constant	0.45	0.06	
Convergent thinking	0.02	0.01	0.28*
2			
Constant	0.50	0.06	
Convergent thinking	0.01	0.01	0.10
Quantitative divergent thinking	0.19	0.05	0.47*

regression (see Table 11), there was a significant 19.3% increase in the explained variance ($\Delta F(1, 49) = 13.03$, $p = 7.18 \times 10^{-4}$). In contrast to qualitative divergent thinking, quantitative divergent thinking was a significant predictor of false recognition ($\beta = 0.47$, $t(51) = 3.61$, $p = 7.18 \times 10^{-4}$). When quantitative divergent thinking was entered as a predictor, the relationship with convergent thinking was no longer significant ($\beta = 0.01$, $t(51) < 1$).

Table 12
Summary of the hierarchical multiple regression analysis for convergent, qualitative divergent thinking, and quantitative divergent thinking in relation to false recognition (*$p < 0.05$).

Step	B	SE B	β
1			
Constant	0.45	0.06	
Convergent thinking	0.02	0.01	0.28*
2			
Constant	0.31	0.17	
Convergent thinking	0.02	0.01	0.26
Qualitative divergent thinking	0.09	0.10	0.12
3			
Constant	0.59	0.17	
Convergent thinking	0.01	0.01	0.10
Qualitative divergent thinking	−0.05	0.10	−0.07
Quantitative divergent thinking	0.20	0.06	0.51*

Table 13
Summary of the hierarchical multiple regression analysis for convergent and quantitative divergent thinking in relation to false recall (*$p < 0.05$).

Step	B	SE B	β
1			
Constant	0.09	0.32	
Convergent thinking	0.004	0.004	0.13
2			
Constant	0.12	0.03	
Convergent thinking	−0.0002	0.005	−0.007
Quantitative divergent thinking	0.07	0.03	0.37*

As in Experiment 1, we ran a three-step regression model with the convergent thinking scores entered at Step 1, the qualitative divergent thinking scores at Step 2, and quantitative divergent thinking scores at Step 3 (see Table 12). This analysis revealed that only quantitative divergent thinking was a significant predictor of false recognition ($\beta = 0.51$, $t(51) = 3.48$, $p = 1.07 \times 10^{-3}$), whereas qualitative divergent thinking and convergent thinking were not ($\beta s < 0.10$, $ts(51) < 1$).

4.2.2. False recall

Neither convergent thinking nor qualitative divergent thinking were significantly correlated with false recall (Fig. 2B, top and middle), and therefore a regression analysis was not conducted on these data. In contrast, quantitative divergent thinking was correlated with false recall (Fig. 2B, bottom, although it did not survive a correction for multiple comparisons). A hierarchical multiple regression (see Table 13) revealed that convergent thinking accounted for a nonsignificant 1.8% of the variance in false recall ($F(1, 50) < 1$). The addition of the quantitative divergent thinking scores in Step 2 resulted in a significant 11.6% increase in the explained variance ($\Delta F(1, 49) = 6.57$, $p = 0.01$). Convergent thinking did not significantly predict false recall ($\beta = -0.01$, $t(51) < 1$), whereas quantitative divergent thinking did ($\beta = 0.37$, $t(51) = 2.56$, $p = 0.01$).

Paralleling the false recognition analyses above. we ran a three-step regression model with the convergent thinking scores entered at Step 1, the qualitative divergent thinking scores at Step 2, and quantitative divergent thinking scores at Step 3 (Table 14). This analysis revealed that only quantitative divergent thinking was a significant predictor of false recall ($\beta = 0.30$, $t(51) = 2.01$, $p = 0.03$), whereas qualitative divergent thinking and convergent thinking were not ($\beta s < 0.21$, $ts(51) < 1$).

4.2.3. True recognition

Replicating Experiment 1, initial correlation analyses (Table 8) revealed a significant correlation between convergent thinking and true recognition with no significant correlation between qualitative or quantitative divergent thinking and true recognition. A hierarchical multiple regression (see Table 15) was conducted with the convergent thinking scores entered at Step 1 and the divergent thinking scores at Step 2. The regression analysis revealed that convergent thinking accounted for 12.8% of the variance in true recognition ($F(1,50) = 7.32$, $p = 9.30 \times 10^{-3}$). When both qualitative and quantitative divergent thinking were entered at Step 2, there was a nonsignificant 6.3% increase in the variance accounted for in true recognition ($\Delta F(2, 48) = 1.87$, $p = 0.17$). Replicating Experiment 1, only convergent thinking was a significant predictor of true recognition ($\beta = 0.30$, $t(51) = 2.14$, $p = 0.04$) whereas qualitative and quantitative divergent thinking were not ($\beta s < 0.25$, $t(51) = 1.61$, $ps > 0.11$).

4.2.4. True recall

As in the true recognition analysis, we ran a hierarchical multiple regression to assess the relationship between true recall and creativity, assuming that convergent thinking would be the strongest and only predictor. Supporting this assumption and the results of the true recognition analyses in Experiment 1 and 2, initial correlation analyses (Table 9) revealed that only convergent thinking was correlated with true recall, and neither qualitative or quantitative divergent thinking were correlated with true recall. The regression analysis (Table 16) revealed that convergent thinking accounted for 13.1% of the variance in true recall ($F(1,50) = 7.51$, $p = 8.48 \times 10^{-3}$). When both qualitative and quantitative divergent thinking were entered at Step 2, there was a nonsignificant 2.3% increase in the variance accounted for in true recall ($\Delta F(2, 48) < 1$). Only convergent thinking was a significant predictor of true recall ($\beta = 0.42$, $t(51) = 2.93$, $p = 5.23 \times 10^{-3}$) whereas qualitative and quantitative divergent thinking were not ($\beta s < 0.05$, $ts(51) < 1$).

5. General discussion

In the current study, we aimed to understand the link between memory distortion (recognition and recall-based false memory in the DRM paradigm) and different forms of creative thinking (convergent thinking, qualitative and quantitative divergent thinking). In Experiment 1, we replicated prior findings by Dewhurst et al. (2011) indicating that rates of false recognition in the DRM paradigm are predicted by convergent thinking performance, but are not correlated with qualitative metrics of divergent thinking. We also observed a novel positive relationship between false recognition and quantitative metrics of divergent thinking. In Experiment 2, we replicated these novel findings. In addition, we found that false recall in the DRM paradigm was predicted by quantitative divergent thinking, but not convergent thinking. Across both experiments true recognition and recall were positively correlated with convergent thinking performance, but were not associated with either qualitative or quantitative divergent thinking performance. We discuss the implications of these findings below.

5.1. False recognition and creativity

Our replication of the Dewhurst et al. (2011) findings provide further support for the idea that false recognition in the DRM paradigm and convergent creative thinking rely on common semantic associative processes. As discussed by Dewhurst et al. (2011), these findings align with the activation monitoring theory of false memory (Roediger et al., 2001) which states that false recognition arises from the activation of semantic associates. This perspective is also consistent with that proposed by the constructive memory framework (Schacter et al., 1998) which states that false recognition can arise from implicit associative responses (i.e., the overt or covert generation of a nonpresented lure word during the encoding of associated word lists). The present findings suggest that the generation of semantic associations has both positive (enhanced convergent creativity) and negative consequences (enhanced false recognition).

Interestingly, false recognition was also predicted by quantitative

Table 14
Summary of the hierarchical multiple regression analysis for convergent, qualitative divergent thinking, and quantitative divergent thinking in relation to false recall (*$p < 0.05$).

Step	B	SE B	β
1			
Constant	0.09	0.03	
Convergent thinking	0.004	0.004	0.13
2			
Constant	0.005	0.08	
Convergent thinking	0.003	0.005	0.11
Qualitative divergent thinking	0.06	0.05	0.17
3			
Constant	0.10	0.09	
Convergent thinking	−0.0002	0.005	−0.007
Qualitative divergent thinking	0.01	0.05	0.03
Quantitative divergent thinking	0.07	0.03	0.36*

Table 15
Summary of the hierarchical multiple regression analysis for convergent, qualitative divergent thinking, and quantitative divergent thinking in relation to true recognition (*$p < 0.05$).

Step	B	SE B	β
1			
Constant	0.54	0.05	
Convergent thinking	0.02	0.007	0.36*
2			
Constant	0.77	0.14	
Convergent thinking	0.02	0.007	0.30*
Qualitative divergent thinking	−0.14	0.09	−0.23
Quantitative divergent thinking	0.08	0.04	0.27

divergent thinking performance. These findings align with the idea that convergent creative thinking and quantitative divergent thinking share some underlying processes (e.g., semantic associative processes). This idea is supported by prior neuroimaging data that convergent and divergent thinking are supported by common neural substrates involved in semantic processes (e.g., Abraham et al., 2012; Beaty et al., 2020; Chrysikou & Thompson-Schill, 2011; Fink et al., 2015; Japardi, Bookheimer, Knudsen, Ghahremani, & Bilder, 2018; Li, Li, Ji, Zhang, & Qiu, 2019; Shen et al., 2016; Wu, Zhong, & Chen, 2016). According to the constructive memory framework (Schacter et al., 1998), false recognition arises from a failure of pattern separation (e.g., Kirwan & Stark, 2007), which likely reflects the reliance on gist information that commonly supports convergent and quantitative divergent thinking.

Of note, the correlations analyses produced different patterns across Experiments 1 and 2 with respect to the relationship between false recognition and convergent thinking (compare Tables 3 and 8). The magnitude of the correlation between convergent thinking and false recognition was larger in Experiment 1 relative to Experiment 2 (i.e., 0.59 relative to 0.28). The inconsistency in the relationship between false recognition and convergent thinking may reflect the impact of the prior recall test on recognition in Experiment 2. We note however that these correlations did not statistically differ ($Z = 1.93$, $p > 0.05$; Preacher, 2002), and the difference may be more apparent than real.

5.2. False recall and creativity

In Experiment 2, we found that false recall was predicted by quantitative divergent thinking performance, with the relationships to either qualitative divergent thinking or convergent thinking not reaching significance. These results align with our previous data demonstrating that quantitative divergent thinking is sensitive to manipulations of episodic processing such as the specificity induction, whereas qualitative divergent thinking and convergent thinking are not (e.g., Madore et al., 2015; Madore et al., 2019; Madore et al., 2016). We have previously interpreted these findings as reflecting the impact of the specificity induction on the retrieval and recombination of episodic details that episodic memory, simulation, and quantitative divergent thinking all recruit. We have previously shown that the specificity induction also boosts false recall in the DRM paradigm (Thakral et al., 2019), providing indirect evidence that the same flexible episodic retrieval processes that support adaptive benefits can also lead to memory errors. Importantly, the current study showed that false recall was predicted only by quantitative metrics of divergent thinking and not by qualitative metrics. This relationship also corroborates our prior specificity induction data indicating that the induction impacts tasks that have a generative component, such as generating remembered past or imagined future autobiographical episodes, false recall, and quantitative metrics of divergent thinking (for a review, see Schacter & Madore, 2016). The current findings add to recent and limited work showing a direct link between the costs and benefits of flexible episodic processes (Carpenter & Schacter, 2017, 2018; Dewhurst et al., 2016).

Table 16
Summary of the hierarchical multiple regression analysis for convergent, qualitative divergent thinking, and quantitative divergent thinking in relation to true recall (*$p < 0.05$).

Step	B	SE B	β
1			
Constant	0.16	0.03	
Convergent thinking	0.01	0.004	0.36*
2			
Constant	0.11	0.09	
Convergent thinking	0.01	0.005	0.42*
Qualitative divergent thinking	0.02	0.06	0.05
Quantitative divergent thinking	−0.04	0.03	−0.18

As noted in the Introduction, according to the constructive memory framework (Schacter et al., 1998), recall is considered a pattern completion process whereby a retrieval cue is internally generated. This retrieval cue can potentially overlap with a memory trace, and therefore complete the pattern and reactivate constituent features of a prior experience. False recall results, in part, from the construction of an incorrect/inappropriate retrieval cue that is consistent with a target memory. Given that quantitative divergent thinking in the AUT also involves the generation of specific information (e.g., specific details to allow the creation of a novel use), the current relationship between false recall and quantitative metrics of divergent thinking likely reflects the common reliance on a pattern completion process.

The false recall findings also align with recent fMRI data indicating that divergent creative thinking recruits neural regions commonly associated with episodic processing, including the hippocampus (e.g., Benedek et al., 2014; Beaty et al., 2018; Thakral et al., 2020; Wu et al., 2015). For example, two prior studies have demonstrated that the specificity induction modulates hippocampal activity, and that these induction-related increases in neural activity are linked to the induction-related behavioral increases in both episodic detail for imagined events and quantitative divergent thinking (Madore et al., 2019; Madore, Szpunar, et al., 2016). Under the assumption that recall, unlike recognition, is a more “process-pure” measure of recollection-based memory (Mandler, 1980; Yonelinas, 2002; Yonelinas et al., 2010), taken together with these fMRI data, our findings suggest that quantitative divergent thinking and false recall are supported by common hippocampal/recollection-based processing (for reviews of evidence linking the hippocampus with false memory, see, Schacter & Slotnick, 2004; Slotnick & Schacter, 2007).

Also consistent with these neuroimaging data are data from patients with bilateral hippocampal damage who have deficits in divergent thinking (Duff et al., 2013). However, some patients with hippocampal damage have also have deficits in tasks tapping convergent thinking

(Warren, Kurczek, & Duff, 2016). These data may reflect a common issue with neuropsychological data in that lesions may not be entirely restricted to a single region. Relevant to this issue, a region proximal to the hippocampus, the perirhinal cortex, has been linked to semantic processing (e.g., O'Kane, Insler, & Wagner, 2005; Voss, Hauner, & Paller, 2009; Wang, Lazzara, Ranganath, Knight, & Yonelinas, 2010; Barense, Henson, & Graham, 2011; Wang et al., 2014). The common divergent and convergent thinking deficits observed in patients with amnesia may reflect, in part, the impact of damage to the perirhinal cortex, because both types of creativity rely on semantic processing. This possibility is supported by the present data: false recognition was predicted by both convergent and quantitative divergent thinking. Recognition memory is thought to rely on both recollection and familiarity-based recognition (Mandler, 1980; Yonelinas, 2002). In contrast to recollection and its well-known link to the hippocampus, familiarity-based recognition has been associated with the perirhinal cortex and semantic processing (e.g., Wang et al., 2010, 2014; for a review, see Dew & Cabeza, 2011), providing a plausible and common neural substrate across false recognition, convergent thinking, and divergent thinking.

5.3. True memory and creativity

Although the primary aim of this study was to examine links between false memory and creativity, we also tested for a relationship between true memory and creative thinking. Replicated across two experiments, rates of true recognition and recall were predicted by convergent thinking performance. Although unexpected given the null relationship observed in Dewhurst et al. (2011) between true recognition and convergent thinking, these findings generally align with our prior specificity induction work showing that the induction facilitates divergent thinking and false recall, but has no impact on convergent thinking or true recall (Madore et al., 2015; Thakral et al., 2019). Taken together, these data suggest that the relationship between true memory and convergent thinking does not reflect common retrieval and recombination-related processing, because those are impacted by the specificity induction. The question remains as to what underlying processes link true memory with convergent thinking. One possible answer comes from the source monitoring framework (Johnson, 2006; Johnson, Hashtroudi, & Lindsay, 1993; Mitchell & Johnson, 2009). Source monitoring refers to the set of control/decision processes that support our ability to attribute the origin or 'source' of memories. One such decision process is criterion setting, where the rememberer sets up a response criterion to weigh the amount or type of information used to make decisions about retrieved information (e.g., to decide whether an event is old or new or if an event occurred or was just imagined). If monitoring criteria are lax, critical lures are subject to errors of source monitoring and incorrectly endorsed as studied. In contrast, when source monitoring criteria are strict, false memories can be reduced. These monitoring and criterion setting processes may commonly support effective true memory and convergent thinking (e.g., the effective weighing of retrieved information in order to make an accurate/true memory response and an accurate response during convergent thinking).

One caveat to this interpretation is that false recognition was also linked to convergent thinking. These findings would suggest that different monitoring processes link true and false memory to convergent thinking. According to Johnson et al. (1993), two types of monitoring processes exist: heuristic decision processes and systematic decision processes. Heuristic processes use much less differentiated input to evaluate retrieved information. Systematic monitoring refers to when detailed or specific information is deliberately and carefully examined to determine its origin. One possibility is that the link between false memory and convergent thinking reflects the engagement of heuristic decision processes as the reliance on less differentiated information may lead to enhanced false memory. In contrast, the link between true memory and convergent thinking may reflect the common engagement of systematic decision processes. This latter distinction aligns with neuroimaging data to suggest that true relative to false recognition and convergent relative to divergent thinking both recruit the inferior parietal cortex suggesting the existence of a common neural substrate supporting systematic decision processing (for reviews, see Slotnick & Schacter, 2007; Wu et al., 2015).

5.4. Limitations and conclusion

One limitation of the present data is that they are restricted to laboratory measures of false memory and creativity. It will be important for future studies to assess whether the present findings extend to more real-world assessments of creativity and memory error. Future studies should also examine whether creativity is linked to other forms of false memory (e.g., source misattribution) because these links could shed light on additional shared constructive memory processes across memory distortion and creative thinking (for a discussion, see Ditta & Storm, 2018). Prior findings suggest that the current link between false memory and creative thinking may be specific to DRM-based false memories. For example, DRM-based errors do not appear to be related to misinformation errors (Calvillo & Parong, 2016; Monds, Paterson, & Kemp, 2017; Ost et al., 2013; Zhu, Chen, Loftus, Lin, & Dong, 2013) and may not relate to some forms of autobiographical memory errors (Patihis et al., 2018 Wilkinson & Hyman, 1998; but see Platt, Lacey, Iobst, & Finkelman, 1998). These findings would provide support for the general idea that there are a multitude of memory errors that may not necessarily be supported by common constructive memory processes (for a discussion, see Hyman, 1999; Roediger, 1996; Patihis et al., 2018; Schacter et al., 2021). An important avenue for future research would be test whether the current link between memory error and creativity is observed outside the DRM paradigm.

A further limitation stems from the fact that the present study employed an individual differences approach which is known to be sensitive to sample size. Although the key results replicated across experiments (and in an additional data set not currently reported[6]), future replication studies are necessary with larger sample sizes. Additionally, the current data are limited in that we only employed a divergent thinking task with a single test item and therefore could not formally examine the internal consistency/reliability of the scores. Importantly, the methods currently employed follow experimental procedures recommended in prior studies employing the AUT which provide reliable divergent thinking scores (see Material and Methods). Lastly, the current recognition data are restricted to old/new recognition memory. It will be interesting for future work to examine how specific types of recognition memory judgments (e.g., by employing the remember/know procedure; Tulving, 1985) are related to each form of creativity. The present data would suggest that recollection-based recognition memory (i.e., 'remember' responses) would likely correlate with divergent thinking, whereas familiarity-based recognition (i.e., 'know' responses) would correlate with both forms of creativity.

An additional avenue for future work would be to employ multiple measures of individual differences in convergent thinking and divergent thinking beyond just the RAT and AUT, respectively. For example, prior theoretical work has identified three cognitive processes that relate to creative thinking: goal-directed memory retrieval, prepotent-response inhibition, and internally-focused attention (Beaty, Seli, & Schacter, 2019). The precise mapping of these cognitive processes onto convergent and divergent thinking may help to identify the specific processes that relate creative thinking to susceptibility to false memory. The current study is an important first step in demonstrating a relationship between convergent and divergent thinking and false memory.

In conclusion, in the present study, we employed an individual differences approach and examined the relationship between different

[6] See Footnote 1.

forms of creative thinking (divergent and convergent thinking) and false memory generation in the DRM paradigm. The current findings suggest that constructive memory processes link creative thinking with the production of memory errors. This work reveals a direct link between the adaptive benefits of constructive episodic retrieval processes, and costs in terms of memory errors.

Funding

This work was supported by National Institute of Mental Health RO1MH060941 and National Institute on Aging R01 AG008441 to DLS.

Data statement

Data and materials are available upon direct request. 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 is required before any data and/or materials will be made available.

Declaration of Competing Interest

None.

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