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Divergent thinking modulates interactions between episodic memory and schema knowledge: Controlled and spontaneous episodic retrieval processes

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Abstract

The ability to generate novel ideas, known as divergent thinking, depends on both semantic knowledge and episodic memory. Semantic knowledge and episodic memory are known to interact to support memory decisions, but how they may interact to support divergent thinking is unknown. Moreover, it is debated whether divergent thinking relies on spontaneous or controlled retrieval processes. We addressed these questions by examining whether divergent thinking ability relates to interactions between semantic knowledge and different episodic memory processes. Participants completed the alternate uses task of divergent thinking, and completed a memory task in which they searched for target objects in schema-congruent or schema-incongruent locations within scenes. In a subsequent test, participants indicated where in each scene the target object had been located previously (i.e., spatial accuracy test), and provided confidence-based recognition memory judgments that indexed distinct episodic memory processes (i.e., recollection, familiarity, and unconscious memory) for the scenes. We found that higher divergent thinking ability—specifically in terms of the number of ideas generated—was related to (1) more of a benefit from recollection (a controlled process) and unconscious memory (a spontaneous process) on spatial accuracy and (2) beneficial differences in how semantic knowledge was combined with recollection and unconscious memory to influence spatial accuracy. In contrast, there were no effects with respect to familiarity (a spontaneous process). These findings indicate that divergent thinking is related to both controlled and spontaneous memory processes, and suggest that divergent thinking is related to the ability to flexibly combine semantic knowledge with episodic memory.

Keywords Creativity · Divergent thinking · Episodic memory · Schema knowledge · Recognition

Imagine that you are trying to generate new, original ideas for experiments to answer a research question of interest. To generate the ideas, you would likely need to draw on both your semantic knowledge for the topic of interest, as well as your episodic memory for recent studies published on the topic. But how are these two sources of information combined to facilitate idea generation? It has long been proposed that semantic knowledge plays a critical role in divergent thinking (Beaty et al., 2014, 2020; Benedek et al., 2017; Benedek, Jauk, Fink et al., 2014a; He et al., 2020; Kenett, 2018; Kenett et al., 2014; Mednick, 1962), which is the ability to generate multiple new ideas (Sternberg & Lubart, 1999). An important role has recently been outlined for episodic memory, as well, in divergent thinking (Beaty et al., 2020; Gilhooly et al., 2007; Madore et al., 2015, 2016, 2019; Thakral et al., 2020). However, it is not yet known whether the manner in which semantic knowledge and episodic memory *interact* is important for the ability to generate new ideas. In the present study, we address this question by examining how divergent thinking ability relates to interactions between semantic knowledge and episodic memory processes.

Our semantic knowledge of the world is the foundation upon which we build ideas. Both the structure of how semantic concepts are represented in memory, and the ability to access that semantic knowledge in a controlled fashion, have been implicated in divergent thinking ability (Beaty et al., 2014; Benedek et al., 2017). For example, individual differences in the ability to retrieve semantic information (i.e.,

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verbal fluency), as well as broad retrieval ability, predict divergent thinking performance (Beaty et al., 2014; Miroshnik et al., 2023; Silvia et al., 2013). Moreover, network analysis of how semantic concepts are represented relative to one another suggests that individuals who are higher in divergent thinking ability have semantic networks that are organized in a more flexible manner (Benedek et al., 2017; He et al., 2020; Kenett, 2018; Kenett et al., 2014). Thus, semantic knowledge appears to play an important role in supporting divergent thinking.

The possibility that episodic memory may also play a key role in divergent thinking is a new but rapidly growing area of investigation. For example, manipulations developed to influence episodic memory have effects on divergent thinking as well: When participants are given episodic specificity inductions, in which they are asked to generate more details when imagining and recalling past memories, participants' subsequent divergent thinking performance improves (Madore et al., 2015, 2016). In particular, the number of ideas that participants generate is increased, rather than the originality of their responses. Interestingly, divergent thinking performance is not improved by control manipulations—such as retrieval of nonspecific information about the same memories—outlining a unique role for episodic specificity in divergent thinking (Madore et al., 2015, 2016). In addition to functional overlap, the neural mechanisms underlying episodic memory retrieval have been shown to support divergent thinking performance as well (e.g., via TMS manipulations; Ellamil et al., 2012; Madore et al., 2019; Thakral et al., 2020). Moreover, recent theories of divergent thinking emphasize the role of broader episodic processes beyond retrieval in idea generation, including episodic simulation processes and false memory (Beaty et al., 2018; Thakral, Yang, et al., 2021b). For example, the number of details provided during episodic simulation of future events predicts divergent thinking ability (Addis et al., 2016; Thakral, Yang, et al., 2021b), and false memory has been associated with divergent thinking as well (Thakral et al., 2023; Thakral, Devitt et al., 2021a; but see Dewhurst et al., 2011). In short, a growing body of work indicates that a variety of episodic memory processes may be involved in divergent thinking.

An important consideration, however, is that episodic memory and semantic knowledge do not proceed in parallel: They are intertwined at both a functional and neural level (Renoult et al., 2019). For example, the extent to which information is in line with semantic knowledge is a strong determinant of whether that information is successfully encoded into episodic memory (Greve et al., 2019; Sweegers et al., 2015; van Kesteren et al., 2012). Moreover, the content of retrieved episodic memories is biased by semantic knowledge, leading memory responses to be more in line with semantic expectations (Hemmer & Steyvers, 2009; Huttenlocher et al., 1991, 2000; Persaud et al., 2021). Particularly relevant for the question of semantic–episodic interactions within divergent thinking, there is evidence that interactions between semantic knowledge and episodic memory are necessary to support future event construction, also referred to as episodic simulation (Irish, 2016, 2020; Renoult et al., 2019). For example, it has been proposed that semantic knowledge serves as a scaffold that organizes the use of episodic memory representations in both retrieval of past events and mental construction of new events (Irish, 2016, 2020; Renoult et al., 2019). However, this framework has yet to be formally considered in the context of divergent thinking, despite the fact that divergent thinking is proposed to involve event construction processes (Addis et al., 2016; Beaty et al., 2018; Benedek et al., 2023; Thakral, Yang, et al., 2021b). Supporting this overlap, divergent thinking performance is associated with the level of detail provided in future event construction tasks, and modulations of episodic networks via TMS affect both divergent thinking and event construction in a similar fashion (Addis et al., 2016; Thakral et al., 2020). Therefore, given that semantic–episodic interactions are strongly implicated in event construction, and event construction is strongly implicated in divergent thinking, examining the role of interactions between semantic knowledge and episodic memory processes in divergent thinking itself may be a fruitful next step in understanding how ideas are generated.

An important nuance of these semantic–episodic interactions—which also intersects with theoretical debates in divergent thinking—is that these interactions critically differ depending on the type of episodic memory involved. Specifically, prevailing theories of episodic memory hold that episodic memory can be supported by multiple underlying processes: *recollection* for specific details of an episode, and *familiarity* for the gist or individual items within an episode (Yonelinas, 2002; Yonelinas et al., 2022; but see Wixted, 2007). Moreover, there is evidence that *unconscious memory* outside of awareness can support experience-driven behavioral changes even in the absence of awareness of that memory[1] (Hannula & Greene, 2012; Hannula & Ranganath, 2009; Ramey et al., 2019; Ryan et al., 2000). Importantly, interactions between semantic knowledge and episodic memory differ depending on which episodic memory process is involved (Lampinen et al., 2000, 2001; Ramey et al., 2022b). In the context of a memory task in which episodic memory and semantic knowledge competed to influence spatial memory recall, we

[1] The extent to which unconscious memory is its own process, or simply an expression of other types of memory (e.g., familiarity) below a threshold of subjective awareness is a subject of debate, and the present treatment is agnostic as to what type of representations or systems might underpin unconscious memory.

found that unconscious memory led to some suppression of semantic influences, familiarity-based memory led to moderate suppression of semantic influences, and recollection-based memory led to complete suppression of semantic influences (Ramey et al., 2022b). These findings suggest that the recruitment of semantic knowledge depends on the type of relevant episodic memory that is available. Thus, conducting a thorough investigation of semantic–episodic interactions in divergent thinking requires separating the underlying episodic processes.

In addition to the memory literature highlighting the importance of separating episodic memory processes, theories of creativity also make indirect but quite strong predictions regarding which type of episodic memory might be most important for divergent thinking. Specifically, long-standing theories of divergent thinking posit that only *spontaneous* retrieval processes are recruited for idea generation, whereas recent theories propose that both spontaneous as well as *controlled* retrieval processes are recruited (Benedek et al., 2023; Benedek & Jauk, 2018; Poincaré, 1914). Although these theories do not directly map onto theories in the episodic memory literature regarding controlled versus spontaneous retrieval processes, recollection is widely accepted to constitute a controlled process, whereas familiarity is characterized as a spontaneous process (Yonelinas, 2002; Yonelinas et al., 2022). Moreover, unconscious memory is also typically characterized as a spontaneous or automatic process (Jacoby & Kelley, 1992). Therefore, examining different episodic retrieval processes is important not only for understanding semantic–episodic interactions in general, but also for informing current debates surrounding divergent thinking.

In terms of specific mechanisms for how semantic–episodic interactions could contribute to divergent thinking, synthesizing prior work from the memory literature and the creativity literature provides concrete testable hypotheses. Abstracting our findings of recollection-induced suppression of semantic knowledge during memory decisions (Ramey et al., 2022b), one potential dynamic is that having strong recollection for a specific idea that one has encountered might suppress the use of other forms of information such as semantic knowledge during divergent thinking. As an example, if asked to generate ideas for how the world might change if we made artificially intelligent robots at a large scale (which is the type of question posed by the consequences task of divergent thinking; Weiss et al., 2021), one might recollect recently watching *The Matrix* and therefore be unable to suppress the relevant ideas that were put forth in the movie. Thus, one's ideas might be largely constrained to those directly related to episodic content from the movie. In contrast, if one only has weak, gist-like memory for the movie, this weaker memory should be less likely to suppress the use of other information such as semantic knowledge. The phenomenon in which one gets "stuck" on previous solutions—such that prior solutions constrain future solutions—has been termed cognitive fixation; the ability to overcome this cognitive fixation has been proposed to play a major role in divergent thinking, and cognitive flexibility more generally has been found to underpin higher divergent thinking ability (Benedek et al., 2023; George & Wiley, 2019; Palmiero et al., 2022; Smith et al., 1993). Synthesizing these findings from memory work and creativity work, therefore, might lead one to predict that someone who is better able to overcome recollection-induced suppression of semantic knowledge may exhibit better divergent thinking as well. Moreover, it is possible that differences in the flexible combination of episodic memory and semantic knowledge more generally may underpin divergent thinking. These possibilities, however, have yet to be tested.

Current research

In the present study, we examined how divergent thinking performance relates to the manner in which semantic knowledge and different episodic memory processes interact. To examine this question, we employed the paradigm and analytic methods we developed in Ramey et al. (2022b) for examining interaction dynamics between semantic knowledge and different episodic memory processes (i.e., recollection, familiarity, and unconscious memory), and examined how these dynamics related to performance in a standard divergent thinking task. Although the role of semantic–episodic interactions would ideally be directly examined *within* divergent thinking, there are currently no valid methods for doing so, and the current standard method in divergent thinking research is to examine correlations between tasks (for reviews, see Benedek et al., 2023; Palmiero et al., 2022). Therefore, as a first step in investigating this highly novel question, we used a multilevel modeling version of the standard task-correlation procedure and leveraged our newly developed and validated semantic–episodic interactions task.

A variety of outcomes would be of interest for adjudicating between prevailing theories on spontaneous versus controlled processes, and providing the first empirical data on semantic–episodic interactions in relation to divergent thinking. In terms of spontaneous versus controlled retrieval processes (Benedek et al., 2023), dominant theories emphasizing the role of spontaneous retrieval processes might lead one to predict that only familiarity and/or unconscious memory, rather than recollection, should relate to divergent thinking performance. In contrast, recent theories that outline a role for both controlled and spontaneous retrieval processes would lead one to predict that recollection, in addition to familiarity and/or unconscious memory, should relate to divergent thinking performance. We hypothesized that both spontaneous and controlled processes would relate to divergent thinking performance. Specifically, we expected that better recollection, as well as familiarity and/or unconscious memory, would relate to better divergent thinking performance.

The question of how semantic knowledge and episodic memory interact in general is still an underexplored question, let alone how these interactions relate to divergent thinking (Benedek et al., 2023). Because of this, the specific dynamics of how semantic knowledge and episodic memory processes might interact to support divergent thinking have not yet, to our knowledge, received formal theoretical consideration nor direct empirical investigation. Thus, our examination of this question is, by necessity, largely exploratory in nature. Based on the dynamics identified in our prior work on how semantic knowledge and episodic memory interact in general (Ramey et al., 2022b), there are at least two types of semantic–episodic interaction dynamics that could relate to divergent thinking performance. The first possibility is that differences in the overall weighting of semantic knowledge versus episodic memory during retrieval—that is, the extent to which someone relies on one source of information versus the other—may predict divergent thinking performance. For example, relying more on episodic memory (irrespective of the underlying process involved) and discounting semantic knowledge during retrieval could relate to better divergent thinking, or vice versa. A second type of dynamic that could play a role in divergent thinking is the extent to which weighting strategies are flexibly modulated between different episodic memory processes (i.e., recollection, familiarity, and unconscious memory) concerning the use of semantic knowledge during retrieval. For example, based on our prior findings that recollection produced complete suppression of semantic knowledge in memory decisions, it is possible that differences in the extent to which recollection suppresses semantic knowledge could be related to divergent thinking, as outlined in the movie example above. That is, continuing to consider probabilistic information (semantic knowledge) even when one has deterministic information available (recollection) could predict better divergent thinking, given that cognitive flexibility predicts better divergent thinking. Overall, we hypothesized that divergent thinking would be related to episodic-process-specific differences in interactions between episodic memory and semantic knowledge, rather than inflexible overall weighting differences.

To examine these possibilities, we investigated how spatial semantic knowledge, in terms of *schema congruency* (i.e., target objects located in semantically congruent vs incongruent locations; Ghosh & Gilboa, 2014; Gilboa & Marlatte, 2017) and episodic memory processes (i.e., recollection, familiarity, and unconscious memory) for scenes interacted to influence memory decisions for where target objects were located in previously viewed scenes. In addition, participants completed the standard divergent thinking task in which they were asked to generate new and creative uses for objects (Guilford, 1967). We then assessed whether performance on the divergent thinking task, in terms of both the number of responses generated (i.e., fluency) and the originality of responses, was related to differences in how schema congruency interacted with the different episodic memory processes to inform spatial memory decisions. We also assessed other creativity-related measures to determine the extent to which effects were specific to divergent thinking versus related to other aspects of creative cognition as well.

Method

Participants

Two-hundred and fifty undergraduate participants completed the experiment for course credit. Given that there is no analogous prior work to our knowledge that examines interactions between semantic knowledge and episodic memory processes as they relate to performance on a creativity task, we based our power analysis on a small effect size of d = .2, and found that 191 participants were required to achieve 80% power to detect this small effect. We collected data from 250 participants who passed preexperimental attention checks to ensure we would have a sufficiently large sample after exclusions.

Participant data were eliminated from analysis for failing attention checks throughout the experiment (24 participants), clicking on the objects during the study phase less than 90% of the time (17 participants), or having atypical mouse coordinates that did not conform to the typical browser output (e.g., from using a tablet rather than computer; six participants). Thus, the final sample consisted of 203 participants (mean age = 19.2 years, age range: 18–37 years; 128 female, 73 male, two nonbinary). Of these, 173 participants identified as White/Caucasian, 37 as Latino/a/x, 12 as multiracial, 11 as American Indian or Alaska Native, nine as Black or African American, nine as Asian or Asian American, and two did not specify their race. All participants provided informed consent prior to participating. All procedures were approved by the university Institutional Review Board.

Apparatus

The alternate uses task (AUT) and questionnaire portions of the study were conducted online using Qualtrics. The memory task was conducted online using JavaScript via jsPsych (de Leeuw, 2015). Participants were instructed to use a computer with a browser size of at least 800 × 600 px. The experiment would not begin if a participant's browser size was less than 800 × 600 px but allowed them to continue once they expanded it sufficiently; this requirement precluded use of a smartphone.

Materials

Alternate uses task

To assess divergent thinking, we used the AUT (Guilford, 1967). Participants were asked to generate as many creative and original uses for a brick as they could within 3 minutes. AUT responses were scored on the total number of uses generated within the allotted time (i.e., fluency) and the originality of the responses. Responses were considered invalid and were removed if they were not words, were not ideas (e.g., simply describing the properties of a brick), or were incoherent or nonresponsive in a way that the raters were unable to confidently ascertain the meaning. Invalid responses made up 2.3% of the individual response data and were removed.

In order to assess originality, four independent judges rated the originality of each response on a scale of 1–5. The judges achieved good inter-rater reliability (Cronbach's $\alpha >$ 0.80). The average number of responses generated by participants was 10.3 ($SD = 5.1$), and the average originality score was 2.0 ($SD = .43$). To form a composite score, we calculated total AUT scores ($M = 20.0$, $SD = 10.3$) for each participant by multiplying their average creativity score by their fluency score for valid responses. Follow-up analyses were also conducted separately for fluency and originality.

Memory task stimuli

The stimuli that were developed and normed for Ramey et al. (2022b) were used. Specifically, the stimuli were 80 photographs of real-world scenes presented in color at a resolution of 800 × 600 pixels. Of these 80 scenes, 60 were presented at study and test (i.e., old scenes), and 20 were presented only at test (i.e., new scenes). We included more old scenes than new scenes to ensure that an adequate number of old scenes were recognized at each level of confidence for analysis. Stimulus presentation was counterbalanced, such that the scenes appeared in different conditions (i.e., presented at both study and test, or used as a new lure during test; see procedure) for different participants to mitigate stimulus effects.

There were five scene categories—kitchens, dining rooms, bedrooms, living rooms, and bathrooms—and a single type of target object was used for each category. In each scene, only one exemplar of the target object was present. Importantly, for a given scene viewed by a given participant, the target was always visually identical and in the same location across repeated viewings. Two versions of each scene were created using Adobe Photoshop (Fig. 1A–D): one with the target object in a schema-consistent location (i.e., congruent scene), and one with the target in an unexpected location (i.e., incongruent scene). The congruent location was consistent across all scenes in a category, such that targets were placed relative to larger objects with which the target objects co-occur with high probability in daily life (Boettcher et al., 2018). In incongruent scenes, on the other hand, the objects were arbitrarily placed in unexpected but physically plausible locations (i.e., on floors, shelves, chairs, etc., rather than floating). Ratings from a separate group of participants confirmed that target objects in incongruent scenes were located in unexpected places, whereas target objects in congruent scenes were located in expected places (Ramey et al., 2022b). The spatial distributions of target locations were similar between scene conditions. For further details on the types of targets used, the placement decisions, and the spatial distributions of target locations, see Appendix.

Scene congruence was manipulated within-subjects such that each participant was presented with half incongruent scenes and half congruent scenes. The congruent and incongruent versions of the scenes were also counterbalanced such that half of the participants saw the congruent version of a given scene, whereas the other half saw the incongruent version of that same scene. Importantly, a given scene was always congruent or incongruent within a given counterbalance, such that the target was always in the same place in a scene viewed across multiple repetitions by a given participant.

Questionnaires

Participants completed questionnaires to assess other aspects of creativity, to allow us to determine whether any effects obtained were specific to divergent thinking or whether they might relate to creativity more broadly. They completed the Creative Achievement Questionnaire (Carson et al., 2005), the Four-Factor Imagination Scale (Zabelina & Condon, 2020), the Short Imaginal Processing Inventory (Huba et al., 1982), and the Spontaneous and Deliberate Mind-Wandering Scales (Seli et al., 2016). To control for general cognitive ability, participants completed the International Cognitive Ability Resource (ICAR; Condon & Revelle, 2014).

Procedure

The experiment lasted approximately one hour and consisted of a memory task, the AUT, and a series of questionnaires.

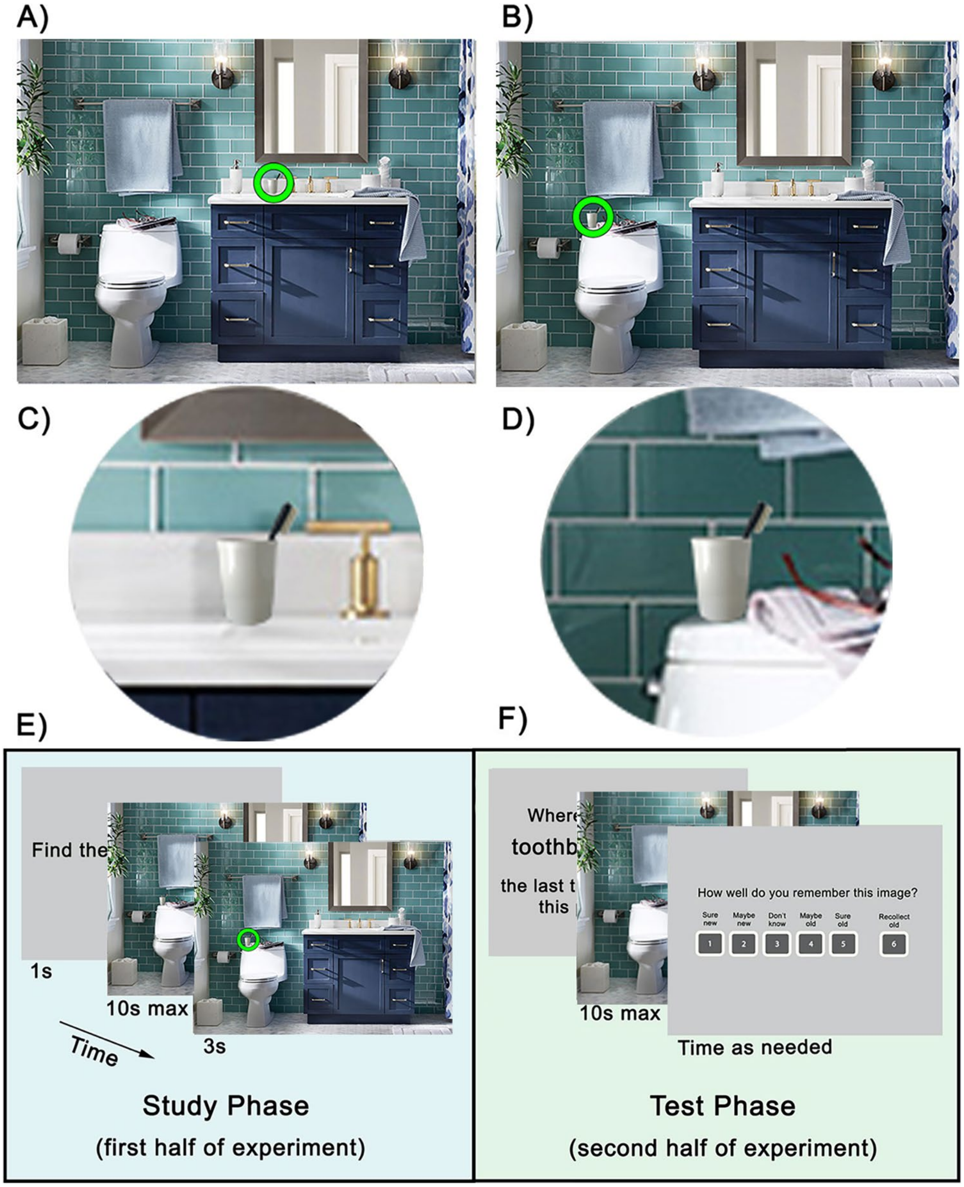

Fig. 1 Sample stimuli and procedure for memory task. *Note.* **A)** The congruent version of a sample scene, with the target object (toothbrush cup) next to the sink. The green ring appeared around the target after participants clicked on the scene in the study phase. **B)** The incongruent version of the scene, with the toothbrush cup on the toilet. **C)** Close-up of the target object in the congruent scene (for visualization only; this was not part of the experiment). **D)** Close-up of the target object in the incongruent scene. **E)** The trial sequence in the study phase, which consisted of 60 scenes presented two times each (120 trials). In each trial, a target probe appeared (e.g., "Find the toothbrush cup"), followed by the scene with target object. Participants were required to click on the target object within 10 s. After clicking or after 10s, whichever occurred first, a green ring appeared around the target for 3 s. **F)** The trial sequence in the test phase, which consisted of 80 scenes (60 old, 20 new; 80 trials). A target probe appeared, followed by the scene without the target object, and participants were given 10s to click on the scene location that they thought had contained the target when the scene was presented in the study phase. After 10s or clicking, whichever occurred first, participants gave a confidence-based recognition memory response for the scene. (Color figure online)

Memory task

The task and procedure from Ramey et al. (2022b) were used. The memory task consisted of a study phase and a test phase. The memory task lasted approximately 45 minutes, and there was a 2-minute break between the study and test phases. Before each phase, participants were given instructions as well as three practice trials to familiarize them with the procedure. Participants were also given a break midway through each phase.

Table 1 Trial counts for each recognition response in old and new scenes

Scene type	Trial counts					
	"Sure new"	"Maybe new"	"Don't know"	"Maybe old"	"Sure old"	"Recollect"
Old	843	1,097	1,186	1,838	2,310	4,898
New	1,503	1,035	585	517	252	164

Study phase Participants were told that they would be searching for and clicking on target objects and were asked to try to remember the scenes and object locations for a later memory test. During the study phase, participants were presented with 60 unique scenes that were each presented twice, for a total of 120 trials. The repetitions were randomly intermixed throughout the study phase, with the requirement that the same scene did not appear twice in a row. In each trial, participants were first given a 1s probe alerting them to the target object they would need to search for. For example, for dining room scenes, the probe was "Find the wine glass." After the probe, the scene appeared, and participants had 10s to click on the target object in the scene. After clicking on the scene, or after 10s had elapsed, a green ring appeared around the target object and remained for 3s to allow participants to study the scene (Fig. 1A–B).

Test phase In the test phase, participants were asked to recall where the target object had been located in each scene when they had seen it during the study phase, and to provide a confidence-based recognition memory judgment for each scene. Participants were told that even if they thought that a scene was new (i.e., not presented in the study phase), they should make their best guess for where the target object might have been if it had in fact been in the study phase—that is, if their episodic memory had failed and it actually was an old scene. The test phase included 80 scenes, 60 of which were presented in the study phase and 20 of which were new lures. Each scene was presented once for a total of 80 test trials. Each trial began with a target probe followed by the presentation of a scene without its target object, and participants were given 10s to click on the location in the scene where they remembered having seen the target object in the study phase. After clicking, or after 10s elapsed, a scene recognition memory response scale appeared and participants were given time as needed to respond.

Episodic memory was measured by asking participants to rate memory confidence for each scene on a 6-point scale during the recognition judgment (Yonelinas, 2002). Participants were told that if they could consciously recollect some qualitative aspect of the initial learning event, such as what they thought about when the scene was encountered earlier, they should respond "Recollect old (6);" otherwise, they rated their memory confidence by responding "I'm sure it's old (5)," "Maybe it's old (4)," "I don't know (3)," "Maybe it's new (2)," or "I'm sure it's new (1)." Importantly, participants were instructed that an "I'm sure it's old" response was equal in confidence to a "recollect old" response, such that the only difference between them was that at least one specific detail of the learning episode was remembered in recollected scenes. Participants were instructed and tested on how to use this scale prior to beginning the test phase.

Data reduction and analysis

Memory task

The primary outcome of interest from the memory task was spatial memory accuracy, assessed via *target distance:* the Euclidean distance between the location clicked by participants during the spatial recall portion of the test phase and the actual location of the target object when the scene was presented in the study phase. This was measured in pixels between the mouse position during the click, recorded in terms of coordinates on the 800 × 600-px scene, and the center of the target object.

The effects of episodic memory were examined by comparing the target distance values between scenes given different recognition responses. (The trial counts for each response type are presented in Table 1.) Specifically, target distance was compared across familiarity-based responses (1–5) to assess familiarity strength, and between recollected and "sure old" responses (6 versus 5) to assess recollection. In order to examine unconscious memory, we compared performance in forgotten old scenes (i.e., "I'm sure it's new" (1) responses) to a memoryless baseline. Note that in "I'm sure it's new" responses, participants are reporting that they are highly confident that they lack conscious memory for those scenes; therefore, any effects of prior experience on spatial recall for the object location in those scenes cannot reasonably be attributed to conscious memory. By exclusion, therefore, any such effects of experience in "I'm sure it's new" scenes can logically be attributed to memory that is not consciously accessible—thus, unconscious memory (for similar strategies for measuring awareness in memory, see Hannula & Greene, 2012; Hannula & Ranganath, 2009; Ryan et al., 2000).

To provide a memoryless baseline for examining unconscious effects, we computed target distance in scenes that were new. Given that new scenes were never presented with a target object, they were not inherently congruent or incongruent and did not have a true target location. Whether a new scene was classified as congruent or incongruent—and therefore, which target location was used for computing target distance—was determined by the condition in which participants in the opposite counterbalance saw the scene during study (i.e., if participants in Counterbalance 1 saw the target as congruent in a scene during the study phase, that scene was considered to be congruent in Counterbalance 2 in which participants saw it as a new scene). Thus, to measure target distance in new scenes, we calculated the distance between the clicked location in the test phase and the target location when it was shown in the study phase for participants in the other counterbalance. Participants' clicks on new scenes represented their best guess for where the target object might have been located based on their semantic knowledge and their knowledge of the experiment. From a participant's point of view, these new scenes were equivalent to old scenes that they had forgotten seeing. Thus, comparisons of target distance between new scenes and "I'm sure it's new" old scenes were used for analyses of unconscious memory effects.

Statistical analysis

As in Ramey et al. (2022b), statistical analyses were conducted using linear mixed-effects models with random intercepts of subject and image, which allowed us to harness trial-by-trial data while controlling for response bias and stimulus effects (see Equation 1, 2, 3 and 4). This multilevel modeling method nests trials within subjects and images (crossed random effects); thus, although we examined trial-level effects, the dependencies between trials were still accounted for. Moreover, the random effects accounted for the fact that divergent thinking scores were a subject-level variable. Random slopes were also tested for each model, but doing so produced singular fits, indicating that the models were overparameterized when random slopes were included. Therefore, random-intercept-only models were retained. (Though note that when including random slopes did produce an appropriately fitting model, the pattern of results was unchanged compared to intercept-only models.) For the replication model of unconscious memory (i.e., not considering creativity effects), new scene condition assignment was done between-subjects (as detailed above), so only random intercepts of subject were used (as in Ramey et al., 2022b).

The models were estimated using the lmerTest package in R (Kuznetsova et al., 2017), and were fit using maximum likelihood. The degrees of freedom and *t* values used were output by the linear mixed effects model for the variables of interest. The degrees of freedom were computed using the Satterthwaite approximation and were rounded to the nearest integer in the manuscript. Effect sizes were calculated as a standardized regression coefficient (β) for continuous variables, and Cohen's *d* for categorical variables as $2t/\sqrt{df}$ (Rosenthal & Rosnow, 1991).

Results

First, to confirm that the manipulations had the intended effects, we examined the overall effects of schema congruency and episodic memory on spatial accuracy. As expected, target distance was lower in congruent than incongruent scenes, $t(15294) = -15.52$, $p < .0001$, $d = -.25$, indicating that schema congruency influenced spatial accuracy (Fig. 2). Moreover, target distance was lower in old scenes than new scenes, demonstrating that episodic memory contributed to spatial accuracy, $t(15640) = -33.73$, $p < .0001$, $d = -.54$. Thus, both schema congruency and episodic memory separately improved spatial accuracy in target location recall.

Controlled versus spontaneous episodic processes

We next examined the extent to which controlled episodic retrieval processes related to divergent thinking performance (in terms of a composite AUT score of fluency × originality) irrespective of schema congruency. To do this, we examined the effectiveness of recollection in improving target distance. To isolate the effects of recollection—that is, controlled processes specifically—from confounding influences of overall memory strength, recollection was compared with strength-matched familiarity (i.e., "sure old" responses; Ramey et al., 2019, Ramey, Henderson et al., 2020a, Ramey, Yonelinas et al., 2020b, 2022b). Replicating our prior findings, we found that when participants recollected old scenes, target distance decreased compared to strength-matched familiarity, $t(6690) = -16.20$, $p < .0001$, $d = -.40$. Interestingly, we found that the difference in target distance between "recollect" and "sure old" responses was larger when AUT scores were higher, $t(6525) = -2.25$, $p = .025$, $d = -.056$ (Eq. 1). That is, in highly divergent thinkers, recollection had a stronger beneficial impact on spatial memory performance compared to strength-matched familiarity. This suggests that more effective or precise controlled episodic retrieval processes are related to divergent thinking.

We next examined the extent to which spontaneous episodic retrieval processes (i.e., familiarity and unconscious memory) related to divergent thinking performance irrespective of schema congruency. First, to probe the contribution of familiarity, we examined how changes in familiarity strength for old scenes produced changes in target distance (Ramey, Henderson et al., 2020a, Ramey, Yonelinas et al., 2020b; Yonelinas, 2002). Replicating our prior work, target

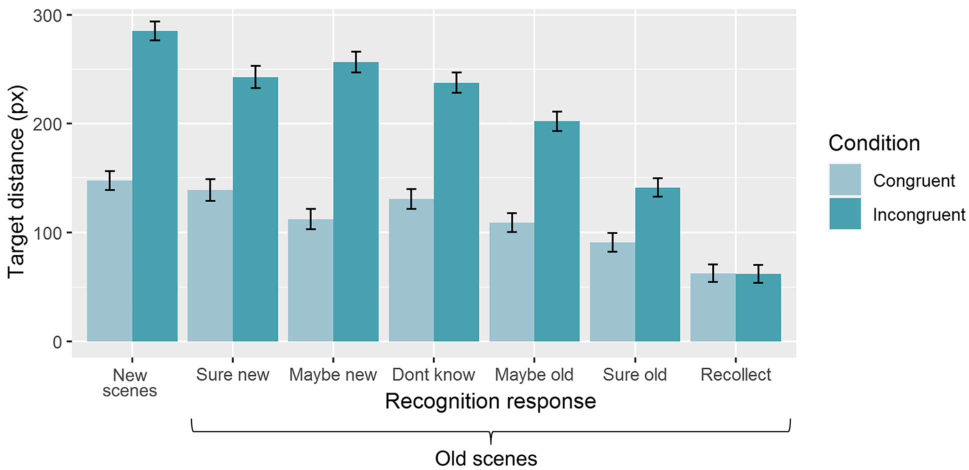

Fig. 2 Overall effects of episodic memory and schema congruency on spatial accuracy. *Note*. Spatial memory accuracy was measured as the distance between the recalled location and the studied object location (i.e., *target distance*). Higher values indicate lower accuracy. The estimated marginal means derived from a linear mixed-effects model with random effects of subject and image are plotted, and the error bars represent the standard error of these estimated means from the model

distance decreased as familiarity strength increased, $\beta = -.16$, $t(6072) = -13.7$, $p < .0001$ (Eq. 3). With respect to divergent thinking, however, AUT score did not significantly moderate how familiarity strength influenced target distance, $\beta = .01$, $t(4588) = .87$, $p = .39$. We assessed the evidence in favor of the null hypotheses using Bayes factors, and found that there was "extreme" evidence for the null effect, $BF_{10} = .004$.[2] This indicates that the contribution of familiarity to spatial accuracy was not related to divergent thinking ability.

Next, we probed the contribution of unconscious memory to spatial accuracy by comparing target distance between old scenes that participants had forgotten ("sure new" responses) and truly new scenes (Eq. 4). As in our prior work, unconscious memory for a target—that is, performance enhancements in "sure new" old scenes compared to new scenes—reduced target distance, $t(4627) = 5.48$, $p < .0001$, $d = -.16$. Importantly, we found that the contribution of unconscious memory to target distance was stronger with increasing AUT scores, $t(2786) = -2.47$, $p = .014$, $d = -.093$ (Fig. 3B). This indicates that stronger or more precise unconscious memory is related to better divergent thinking ability. The discrepancy between familiarity and unconscious memory results suggests that the involvement of spontaneous episodic retrieval processes in divergent thinking might vary depending on the specific retrieval process. Overall, the results thus far indicate that both controlled and spontaneous episodic retrieval processes are related to divergent thinking, in line with emerging theories (Benedek et al., 2023).

Interactions between episodic memory and schema congruency

To examine how divergent thinking relates to interaction dynamics between episodic memory and semantic knowledge, we separately examined each episodic memory process and its interactions with schema congruency. First, we found that recollection suppressed congruency effects in the sample overall (Fig. 2), in line with our prior findings (Ramey et al., 2022b). That is, when scenes were recollected, there was no significant effect of congruency on target distance, $t(4188) = 1.85$, $p = .07$, $d = .057$, such that schema congruency no longer significantly influenced spatial accuracy. However, divergent thinking moderated this effect: AUT score interacted with congruency to predict target distance in recollected scenes, $t(4707) = 2.46$, $p = .014$, $d = .072$ (Fig. 3A; Eq. 2). Specifically, higher divergent thinking scores predicted increased congruency effects within recollected scenes. Importantly, congruency effects were increased in a way that improved performance in more highly divergent thinkers: Within recollected scenes, higher AUT scores predicted significantly better spatial accuracy within congruent scenes, $t(173) = -2.60$, $p = .010$, $d = -.39$, without any significant difference in spatial accuracy within incongruent scenes, $t(172) = -.49$, $p = .62$, $d = -.07$. Thus, when highly divergent thinkers recollected scenes, their spatial accuracy was more influenced by schema congruency in a way that improved performance.

In terms of familiarity, the effects of schema congruency on spatial accuracy were reduced by familiarity such that as

[2] By convention, a $BF_{10} < 0.33$ indicates substantial evidence for the null hypothesis, and a $BF_{10} < 0.01$ indicates extreme evidence for the null (Jeffreys, 1961).

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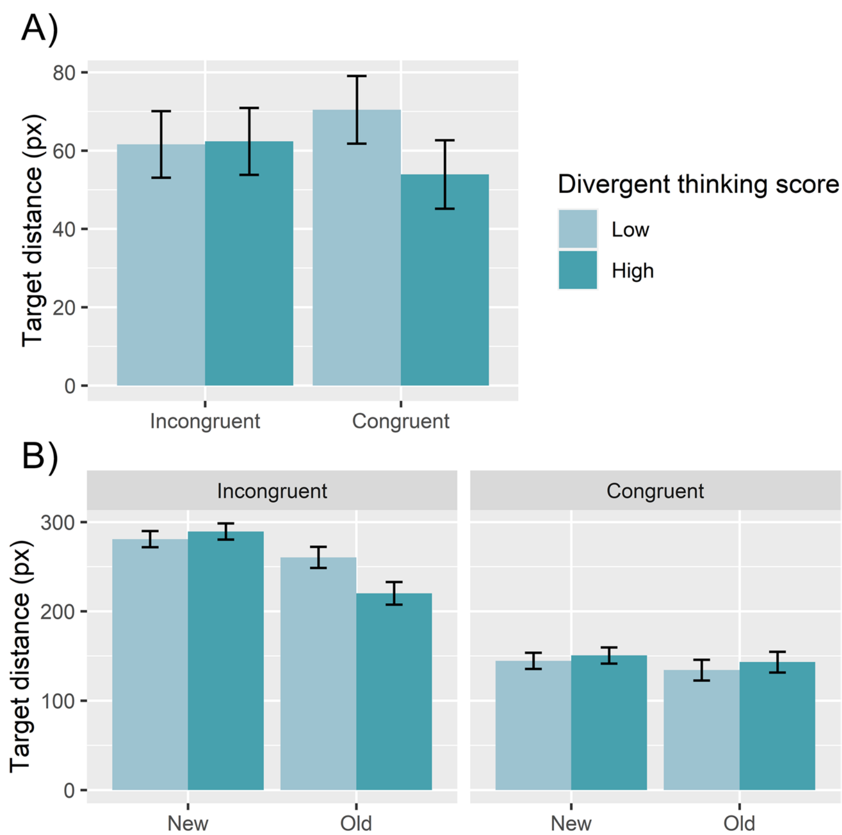

Fig. 3 Recollection and unconscious memory effects on spatial accuracy, by congruency and divergent thinking performance. *Note.* **A**) Effects within recollected scenes. **B**) Unconscious memory effects. Given that participants were highly confident that they had not seen these old scenes (i.e., they gave "I'm sure it's new" responses), differences in spatial accuracy between new scenes and these forgotten old scenes were considered to be driven by unconscious memory. Both plots: Divergent thinking was treated as continuous for all analyses, but was dichotomized for illustration to facilitate comparison with the effects in Fig. 2 and Ramey et al. (2022b). The estimated marginal means derived from the linear mixed effects model are plotted, and the error bars represent the standard error of these estimated means from the model

familiarity strength increased, congruency effects decreased, $\beta = -.08$, $t(7000) = -7.84$, $p < .0001$, replicating our prior findings (Ramey et al., 2022b). AUT score did not significantly moderate how familiarity strength interacted with schema congruency, $\beta = -.007$, $t(6951) = -.73$, $p = .47$ (Eq. 3). Moreover, AUT score did not significantly moderate congruency effects on spatial accuracy within familiar scenes overall—that is, all familiar scenes collapsed across familiarity strength—$\beta = .005$, $t(6903) = .45$, $p = .65$. We assessed the evidence in favor of the null hypotheses using Bayes factors, and found that there was "extreme" evidence for both null effects, BF_{10}s < .002. Thus, there is very strong evidence that divergent thinking ability was not related to familiarity-based episodic memory.

Next, we examined how divergent thinking performance was related to unconscious memory (Eq. 4). Replicating prior work (Ramey et al., 2022b), the effects of congruency on spatial accuracy were reduced by unconscious memory such that when scenes were old but endorsed as "sure new," congruency effects were smaller than for truly new scenes, $t(4625) = -2.88$, $p = .004$, $d = -.085$. This effect was moderated by divergent thinking: When AUT scores were higher, the suppression of schema congruency effects by unconscious memory was stronger, $t(4583) = -2.91$, $p = .004$, $d = -.086$ (Fig. 3B). Importantly, congruency effects were reduced in a way that improved performance. That is, unconscious memory led to larger spatial accuracy improvements in incongruent scenes in highly divergent thinkers, $t(2269) = -4.01$, $p < .0001$, $d = -.17$, but the effect of unconscious memory on spatial accuracy in congruent scenes did not vary with divergent thinking ability, $t(2303) = -.42$, $p = .68$, $d = -.017$. Therefore, analogous to the effects obtained with respect to recollection, divergent thinking was related to an increased benefit of unconscious memory for spatial accuracy overall, and divergent thinking moderated the interaction between unconscious memory and schema congruency such that it predicted improved performance. In contrast to the recollection result, however, the performance improvement related to unconscious memory was driven by a reduction in detrimental schema bias (in incongruent scenes) rather than increased beneficial schema effects (in congruent scenes).

Sensitivity analyses

Thus far, a composite AUT score (fluency × originality) has been used in analyses to index divergent thinking. To assess which aspects of divergent thinking drove the effects outlined above, we reran the analyses separately for the number of responses generated (i.e., fluency) and the rater-determined originality scores. We found that the results were primarily driven by the fluency of divergent thinking, such that the moderating effects of AUT performance on recollection and unconscious memory—both the main memory effects and the interactions with schema congruency—were significant when fluency alone was used as the measure of divergent thinking, *p*s < .05 (Eqs 1, 2, 3 and 4). In contrast, the effects were not significant when originality of responses was used as the only measure of divergent thinking, *p*s >.24. As for the familiarity results that were not significant using the composite AUT score, familiarity was also not related to fluency or originality on their own, *p*s > .22. Thus, all results held when fluency was used as the only predictor.

We next examined how including the composite AUT score in addition to fluency improved model fit beyond including fluency alone, using an ANOVA to compare the fits of the different linear mixed-effects models. Adding the composite AUT score variable to the models of recollection—both the main memory effect and the interaction with congruency (Eqs. 1 and 2)—marginally improved model fits above examining fluency alone, *p*s < .06. Interestingly, adding originality (instead of the composite AUT score) to the models of fluency marginally improved the main recollection effect model, *p* = .07, but did not even marginally improve the model of recollection interactions with schema congruency, *p* = .15—suggesting that there may be additional utility in the multiplicative aspect of the composite AUT score. For unconscious memory, adding the composite AUT score (or originality) to the models of unconscious memory (Eq. 4) did not improve model fits above fluency alone, *p*s > .25. This indicates that the use of the composite AUT score provided a marginal advantage above examining fluency alone for models examining recollection, but not unconscious memory. Overall, however, the number of ideas that participants generated were the primary driver of the divergent thinking effects we found.

We also assessed the robustness and specificity of the observed effects by examining whether they held when controlling for overall cognitive ability, and whether they were related to other types of creativity as well as mind wandering. First, all divergent thinking effects held when controlling for overall cognitive ability, *p*s < .05, indicating that the relationship between divergent thinking and episodic memory was not driven by differences in overall cognitive ability, nor by how much effort participants were putting into the experimental tasks. As for the specificity of effects, the overall effect of recollection was not observed with respect to mind wandering or creative achievement, *p*s > .10, but it was observed with respect to the Four-Factor Imagination Scale and the Short Imaginal Processing Inventory—though this was driven by poorer familiarity rather than better recollection (i.e., the opposite of what was found with AUT), *p*s < .05. The recollection congruency effects found in AUT were not observed with respect to imagination, creative achievement, or mind wandering, *p*s > .15. We found that the unconscious effects were unique to divergent thinking, *p*s > .06; mind wandering, however, exhibited the opposite effect as divergent thinking on the interaction of unconscious memory with schema congruency, *p*=.023. Together, the results indicate that higher divergent thinking, in particular, is related to beneficial differences in recollection and unconscious memory, both in general and in how they interact with semantic knowledge.

Discussion

In the present study, we successfully replicated our prior findings of tradeoffs between schema knowledge and different episodic memory processes in informing memory decisions (Ramey et al., 2022b), and extended them by further examining how these dynamics related to divergent thinking ability. We found that divergent thinking fluency was related to how schema knowledge interacted with episodic memory to influence spatial memory decisions, as well as overall differences in how different episodic memory processes contributed to spatial memory. Specifically, we found that when participants generated more ideas on a divergent thinking task, they (1) exhibited a stronger beneficial influence of recollection (a controlled retrieval process) on spatial accuracy overall, and an increased use of schema information within recollected scenes in a way that benefitted performance, and (2) exhibited a stronger beneficial influence of unconscious memory (a spontaneous retrieval process) on spatial accuracy overall, and unconscious memory was more effective at preventing detrimental schema bias. In contrast to recollection and unconscious memory, we found strong Bayesian evidence that there was no relationship between familiarity-based episodic memory and divergent thinking. These effects were not driven by individual differences in overall cognitive ability or effort, and they were unique to divergent thinking in that they were not observed with respect to other types of creativity. The present results extend prior work suggesting that both semantic knowledge and episodic memory are involved in divergent thinking (Beaty et al., 2020; Benedek et al., 2017; Kenett et al., 2014; Madore et al., 2015), and our findings further suggest that both controlled and spontaneous episodic retrieval processes are involved in divergent thinking. In particular, our findings are the first to our knowledge to show that the *interaction* between semantic knowledge and episodic memory—rather than each simply operating in parallel—is related to divergent thinking ability.

A growing body of work suggests that divergent thinking involves top-down control of a variety of cognitive processes aimed at optimizing retrieval of ideas while inhibiting unoriginal ideas (Benedek, Jauk, Sommer et al., 2014; Nusbaum & Silvia, 2011; Zabelina et al., 2016). For example, compelling evidence has been found for the role of attention (Zabelina et al., 2015, 2016), cognitive control (Benedek, Jauk, Sommer et al., 2014; Zabelina & Ganis, 2018), working memory (Lee & Therriault, 2013; Takeuchi et al., 2011), verbal fluency (Beaty et al., 2014; Silvia et al., 2013), and fluid intelligence (Beaty et al., 2014; Frith et al., 2021) in supporting divergent thinking. The present results, however, extend emerging research investigating the role of episodic memory in divergent thinking ability (Beaty et al., 2020; Gilhooly et al., 2007; Madore et al., 2019; Thakral et al., 2020). In particular, the role of different episodic memory processes in divergent thinking has not, to our knowledge, been examined previously—and our findings suggest that recollection and unconscious memory, but not familiarity, function differently in those with high divergent thinking ability. This finding supports recent theories that both spontaneous and controlled retrieval processes underpin divergent thinking (Benedek et al., 2023). These results are also in agreement with prior findings that the fluency of divergent thinking (i.e., the number of ideas generated), rather than the creativity of ideas, is most strongly related to episodic memory (Madore et al., 2015, 2016). Future work examining other facets of divergent thinking, such as the flexibility of ideas, will be important for a more comprehensive understanding of how episodic memory relates to divergent thinking.

The present relationship of divergent thinking with interactions between recollection and semantic knowledge, and between unconscious memory and semantic knowledge, may reflect two sides of the same coin; that is, cognitive fixation could potentially underpin both effects. As highlighted earlier, cognitive fixation and flexibility are thought to play an important role in divergent thinking (Benedek et al., 2023; George & Wiley, 2019; Palmiero et al., 2022; Smith et al., 1993), and it is possible that higher cognitive flexibility could produce the increase we observed in the use of semantic knowledge even when recollection was available. That is, recollection was the most deterministic source of information available, but participants higher in divergent thinking were more likely to incorporate probabilistic semantic knowledge into their decisions anyway—in a way that improved spatial accuracy overall. As for unconscious memory, the most deterministic source of information to use in this case was semantic knowledge, given that participants were highly confident they had never seen the stimulus before and therefore had no conscious memory for it. Despite this, participants who were higher in divergent thinking ability were less likely to be biased by semantic knowledge when unconscious memory was available—again in a way that improved performance. This suggests that their responses in these forgotten scenes were less informed by knowledge they were aware of (semantic knowledge), and were more informed by memory they were unaware of (unconscious memory), which was likely experienced as a guess (e.g., based on feedback from participants, "this spot would be unusual but it just feels right" was a common experience). Thus, participants higher in divergent thinking ability appeared better able to leverage unconscious memory to overcome constraining effects of schema congruency. Similar to memory decisions, generating ideas requires overcoming the constraining effects of the most automatic or deterministic information available. Given that ideas are constructed from semantic knowledge and episodic memory, therefore, the ability to flexibly combine these two sources of information may play a role in divergent thinking.

The present findings of selective moderation of recollection and unconscious memory by divergent thinking ability, both overall and with respect to interactions with semantic knowledge, are also in line with emerging work implicating the hippocampus in divergent thinking (Beaty et al., 2018; Thakral et al., 2020). That is, recollection is known to rely on the hippocampus and there is increasing evidence that unconscious memory for relational information (such as target–scene relationships) may rely on the hippocampus as well, whereas it has been found that familiarity is not hippocampus-dependent (Bastin et al., 2019; Eichenbaum et al., 2007; Hannula & Greene, 2012; but see Squire et al., 2007; Wixted et al., 2010). In each of the presently observed effects, higher divergent thinking performance predicted improved outcomes of combining hippocampus-based episodic memory with semantic knowledge, such that spatial accuracy was enhanced—whether it involved amplifying semantic knowledge when it was useful for performance (in recollected congruent scenes), or inhibiting semantic knowledge when it was detrimental to performance (in unconsciously remembered incongruent scenes). Moreover, divergent thinking was related to better hippocampus-based memory overall, separately from semantic knowledge interactions. Therefore, hippocampus-based memory may play a particularly important role in divergent thinking.

Many theories of creativity posit a role for unconscious processes in idea generation (e.g., Andreasen, 2011; Ritter et al., 2012; Ritter & Dijksterhuis, 2014). However, perhaps due to the difficulty inherent in isolating them from influences of weak conscious processes, the role of unconscious processes in divergent thinking has not yet, to our knowledge, been measured directly. Although not directly equivalent to the unconscious processes proposed in prior theories of creativity, unconscious memory may provide a unique window through which we can begin to understand the role of unconscious processes in divergent thinking, given that objective effects of unconscious memory on performance can be measured directly. In addition, the recently developed confidence-based method we employed allows unconscious memory to be isolated from contaminating influences of weak conscious memory (Ramey et al., 2019, Ramey, Henderson et al., 2020a, 2022a, 2022b). That is, we assessed unconscious memory by examining how experience with a stimulus changes performance (i.e., spatial accuracy) in the absence of conscious memory (i.e., when participants report with high confidence that they have not seen the stimulus before)—thus, effects of unconscious memory were assessed by ruling out potential influences of conscious memory. Therefore, in addition to the presently identified relationship between unconscious memory and idea generation providing indirect support for theories of unconscious processing in creativity, the present method may prove useful for future studies of unconscious processing in creativity as well.

There are a number of limitations to the present study that should be noted. First, the most widely used version of the AUT was used (Guilford, 1967), which in its standard form presents participants with only a single object. Due to time constraints with the intensive memory task and variety of covariates, we were not able to include additional items. Future studies using a multi-item AUT are warranted to increase reliability, particularly for the originality measure. Second, although the present study draws on prior causal work showing that episodic specificity manipulations and TMS of memory networks influence divergent thinking (Madore et al., 2015; Thakral et al., 2020), the present results cannot speak to causality. That is, although we conceptualize our results as identifying the most likely processes involved in previous causal effects, our findings could still be driven by a number of mechanisms. One possibility is that flexibly combining episodic memory with semantic knowledge is a mechanism underlying divergent thinking. This possibility is in line with prior causal work on episodic memory (e.g., Madore et al., 2015; Thakral et al., 2020). As an alternative possibility, however, it could be that those who are better at divergent thinking happen to exhibit episodic memory differences due to a third factor such as hippocampal integrity or aspects of overall cognitive flexibility that were not captured by our covariates, for example. Future studies are needed to tease apart these possibilities.

In sum, the ability to generate new and original ideas is a complex process that depends on a variety of underlying cognitive processes. The present study suggests that in addition to exerting separable effects on divergent thinking (e.g., Madore et al., 2015), these cognitive processes—in particular, semantic knowledge and episodic memory—may also interact with each other in distinct ways in those who excel at divergent thinking.

Appendix

Additional information about stimuli

The scene categories and targets consisted of kitchens (target: frying pan), dining rooms (target: wine glass), bedrooms (target: alarm clock), living rooms (target: coffee mug), and bathrooms (target: toothbrush cup). Eight different object exemplars were used per category, such that the visual features of the target object varied across different scenes within a category. In each scene, only one exemplar of the target object was present, and this was kept consistent across presentations. For example, in each living room scene, there was only one coffee mug present.

The congruent location for a target object was semantically consistent across all scenes in a category, such that targets were placed relative to larger objects with which the target objects co-occur with high probability in daily life (Boettcher et al., 2018; for review of scene grammar see Võ et al., 2019). Specifically, in bathroom scenes, the toothbrush cups were located next to sinks; in dining room scenes, the wine glasses were located on tables (within arm's reach of a chair); in kitchen scenes, the pans were on stove burners; in bedroom scenes, the alarm clocks were on nightstands; and in living room scenes, the coffee mugs were on coffee tables. The spatial locations of the targets varied across scenes, as illustrated in Fig. 4.

Search time

The target was found on 98.9% of study phase trials. On trials in which the target was found, the average search time was (1) 2045 ms in congruent scenes and 2476 ms in incongruent trials ($p = .0001$), and (2) 2,482 ms on first presentation and 2,040 ms on second presentation ($p < .0001$). Thus, both semantic knowledge and episodic memory contributed to search speed in a similar fashion as to spatial accuracy.

Model equations

The equations for the models used for the primary (i.e., non-replication) analyses are specified below (Eqs 1–4). When these equations are discussed with respect to examining fluency and originality separately (in the Sensitivity Analyses section), the "AUT score" variable below was replaced with "fluency" or "originality," depending on the analysis in question.

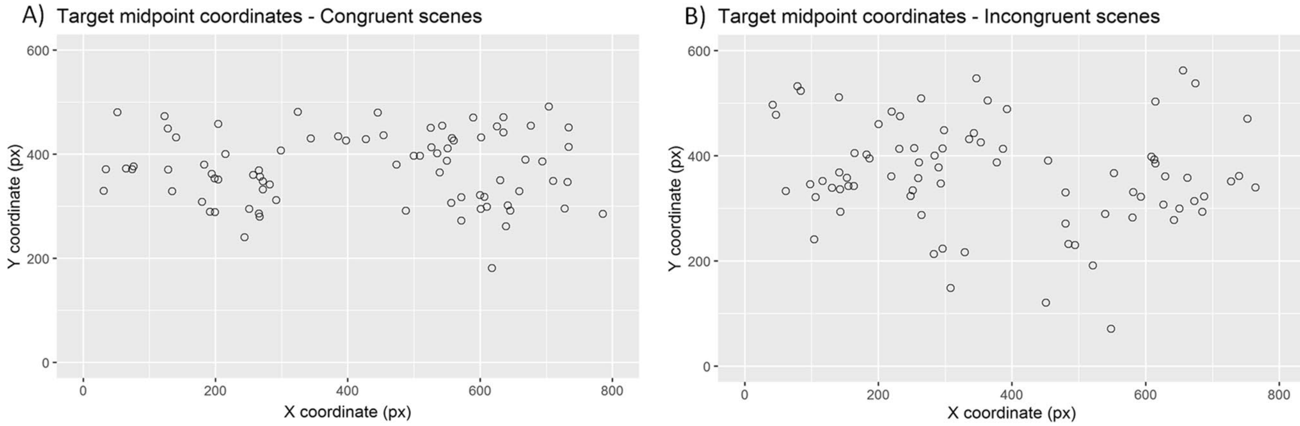

Fig. 4 Distributions of target location midpoints within scenes. *Note.* **A)** Distribution of the target locations in congruent scenes. **B)** Distribution of target locations in incongruent scenes

Recollection effects

For the difference between recollected and strength-matched familiar scenes, the analysis included old scenes that were given a response of 6 or 5, and the model was specified as:

$$\begin{aligned}&\textit{Target distance} \sim \textit{response}\\&* \textit{AUT score} + \textit{image intercept} + \textit{subject intercept}\end{aligned} \quad (1)$$

For the congruency effects, the analysis included recollected scenes (old scenes that were given a response of 6) and was specified as:

$$\begin{aligned}&\textit{Target distance} \sim \textit{congruency}\\&* \textit{AUT score} + \textit{image intercept} + \textit{subject intercept}\end{aligned} \quad (2)$$

Familiarity effects

For familiarity effects, the analyses included scenes across all levels of familiarity strength (old scenes that were given a response of 1-5). For the analysis that examined familiarity irrespective of congruency, the congruency parameter was removed:

$$\begin{aligned}&\textit{Target distance} \sim \textit{congruency} * \textit{AUT score} * \textit{response}\\&+ \textit{image intercept} + \textit{subject intercept}\end{aligned} \quad (3)$$

Unconscious effects

For unconscious effects, analyses were conducted in old scenes given a response of "sure new," and new scenes. For the analysis that examined unconscious memory irrespective of congruency, the congruency parameter was removed:

$$\begin{aligned}&\textit{Target distance} \sim \textit{congruency} * \textit{AUT score}\\&* \textit{old vs new} + \textit{image intercept} + \textit{subject intercept}\end{aligned} \quad (4)$$

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Data availability The experiment was not preregistered. The data and code are available upon request.

Declarations

Conflicts of interest The authors have no financial or proprietary interests in any material discussed in this article.

Ethics approval and consent The methodology for this study was approved by the University institutional review board. Informed consent was obtained from all participants.

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