Creative people use memory differently:

Divergent thinking modulates how episodic memory is combined with semantic knowledge

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Abstract

The ability to generate novel ideas, known as divergent thinking, is dependent on both semantic knowledge and episodic memory. Semantic knowledge and episodic memory are known to interact to support memory decisions, but it is not known how they may interact to support divergent thinking. We addressed this question by examining whether divergent thinking ability moderates interactions between semantic knowledge and different episodic memory processes in a spatial memory task. Participants completed the Alternative Uses Test to assess divergent thinking ability, then completed a memory task in which they searched for target objects that were either placed in semantically expected or semantically unexpected 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), then provided confidence-based recognition memory judgments that indexed distinct episodic memory processes (i.e., recollection, familiarity strength, and unconscious memory) for the scenes. We found that higher divergent thinking ability predicted 1) an increased benefit from putatively hippocampus-based episodic memory (i.e., recollection and unconscious memory) on spatial accuracy overall, 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 of divergent thinking with respect to non-hippocampal memory (i.e., familiarity). These findings indicate that semantic knowledge and episodic memory function differently in highly divergent thinkers. In particular, these results suggest that divergent thinking is supported by the ability to flexibly combine semantic knowledge with episodic memory, particularly hippocampus-based memory.

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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 constructs 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., 2014; 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 how semantic knowledge and episodic memory *interact* to allow for the generation of ideas. In the present study, we address this question by examining how divergent thinking ability relates to the interaction between semantic knowledge and episodic memory.

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 shown to contribute to divergent thinking ability (Beaty et al., 2014; Benedek et al., 2017). For example, individual differences in the ability to retrieve semantic information (i.e., verbal fluency) predict divergent thinking performance in terms of both the creativity of ideas and the number of ideas generated (Beaty et al., 2014; 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, in that their semantic networks are more connected and less modular (Benedek et al., 2017; He et al., 2020; Kenett, 2018; Kenett et al., 2014). Additionally, giving participants a semantic induction—in which participants are oriented towards semantic processing—increases the creativity of subsequent divergent thinking responses (Beaty et al., 2020). Thus, both examinations of individual differences and manipulations of semantic retrieval orientation converge to outline a key role for semantic knowledge in supporting divergent thinking.

The possibility that episodic memory, in addition to semantic knowledge, may also play a key role in divergent thinking is a new but rapidly growing area of investigation. For example, it has been shown that 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 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. The neural mechanisms underlying episodic memory retrieval have been shown to support divergent thinking performance as well (Madore et al 2019), and disruption of episodic memory networks impairs divergent thinking without influencing performance on a nonepisodic control task (Thakral et al., 2020). Based on these findings, it has been proposed that divergent thinking may involve constructive episodic retrieval mechanisms (Madore et al., 2019; Thakral et al., 2020). However, it is not yet clear whether individual differences in divergent thinking ability relate to differences in episodic memory functioning.

While episodic memory and semantic knowledge have each separately been implicated in divergent thinking, these processes are not entirely independent; rather, they are known to

influence one another. For example, work with Bayesian models of memory has shown that episodic memory is consistently biased by schema information, even for simple perceptual memory (Hemmer & Persaud, 2014; Hemmer & Steyvers, 2009; Huttenlocher et al., 1991). Recent work also suggests that semantic knowledge and episodic memory may compete with each other, such that stronger episodic memory reduces the influence of semantic meaning on attentional deployment via eye movements (Ramey, Yonelinas, et al., 2020) and reduces the influence of schema knowledge on spatial memory decisions in scenes (Ramey et al., 2021). These latter effects also vary depending on the episodic memory process involved: *Unconscious memory* outside of awareness as well as a vague sense of *familiarity* exert some suppression of schema knowledge, whereas vivid *recollection* is uniquely able to eliminate schema effects entirely (Ramey et al., 2021). These three episodic memory processes have been shown to be both functionally and neurally distinct in prior work (Eichenbaum et al., 2007; Voss et al., 2010; Yonelinas, 2002), but it is not yet known how they relate to divergent thinking or even creativity more generally. More importantly, even though the interactions between semantic knowledge and episodic memory processes have been shown to exert important effects on behavior, it is not known how they interact to support divergent thinking.

Current research

In the present study, we addressed these questions by examining how divergent thinking performance relates to the manner in which semantic knowledge and episodic memory interact. Specifically, we investigated how spatial schema knowledge and recognition memory processes are combined to influence memory decisions for where a target object was located in a previously viewed scene. In addition, participants completed a divergent thinking task—the Alternative Uses Test (AUT; Guilford, 1967)—in which they were asked to generate new and

creative uses for a common object. We then assessed whether performance on the divergent thinking task was related to differences in how participants combined schema knowledge with different episodic memory processes (i.e., recollection, familiarity, and unconscious memory).

Prior to the memory task, participants completed the AUT, and responses were scored both in terms of how many uses were generated, as well as how creative those uses were. Subsequently, participants completed the memory task. In the first half of the memory task (i.e., the *study phase*), participants searched for target objects in scenes. Half of these scenes contained the target object in a schema-congruent location (e.g., toothbrush next to sink), and half contained the target object in a schema-incongruent location (e.g., toothbrush next to bathtub; see Figure 1). During a subsequent *test phase*, participants were shown a mixture of new and studied scenes that did not contain the target object and were asked to indicate the precise location that had contained the target object during the study phase. After making this spatial memory decision, participants were then asked to report their recognition memory for the scene using a confidence-based response scale that indexes recollection, familiarity, and unconscious memory (Ramey et al., 2019; Ramey, Henderson, et al., 2020). Thus, the memory task allowed for assessment of how semantic knowledge (i.e., the schema congruency of objects) and episodic memory (i.e., participants' recognition memory for the scene) jointly influenced spatial memory accuracy (i.e., participants' target location decision). Participants also completed additional questionnaires assessing other aspects of creativity as well as a cognitive abilities measure, which allowed for assessment of whether any effects obtained were specific to divergent thinking performance.

Given that episodic memory processes—or their interaction with semantic knowledge—have not yet been examined with respect to divergent thinking, a variety of outcomes would be

of interest. First, in light of prior work showing that episodic specificity inductions improve the fluency of divergent thinking (Madore et al., 2015), it is possible that differences in how semantic knowledge interacts with recollection, which is uniquely able to support memory for details, would be particularly related to divergent thinking performance. This could lead to differences in how recollection influences the use of semantic knowledge, such that divergent thinking may modulate the extent to which recollection suppresses schema congruency effects on spatial accuracy (Ramey et al., 2021). Moreover, given findings of the hippocampus being involved in divergent thinking (Madore et al., 2019), we hypothesized that divergent thinking may be most strongly related to how hippocampus-based memory—namely recollection, and perhaps unconscious memory (Eichenbaum et al., 2007; Hannula & Greene, 2012)—is combined with semantic knowledge. Thus, in addition to recollection-related effects, differences in hippocampus-based memory in divergent thinking could also influence how unconscious memory interacts with schema congruency. Lastly, it is possible that divergent thinking may relate to the interaction between familiarity strength—which relies on regions outside the hippocampus—and schema congruency as well, but the lack of relevant prior work does not allow for strong hypotheses with respect to familiarity.

Method

Participants

Two-hundred and three participants successfully completed the experiment for course credit. Given that there is no analogous prior work to our knowledge that examines interactions between 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 would be required to achieve 80% power to detect this small effect. We collected data from 250 participants who

passed pre-experimental attention checks to ensure we would have a sufficiently large sample after exclusions. Participant data were eliminated 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; 6 participants). Thus, the final sample consisted of 203 participants. All participants provided their informed consent prior to participating.

Apparatus

The Alternative Uses Test (AUT) and questionnaire portions of the study were conducted online using Qualtrics. The memory task was conducted online using Javascript via JSpsych, which allows for accurate, high-speed presentation timing and response recording (de Leeuw, 2015). Participants were instructed to use a computer with a browser size of at least 800x600px. The experiment would not begin if a participant's browser size was less than 800x600px but allowed them to continue once they expanded it sufficiently; this requirement precluded use of a smartphone.

Materials

Alternative Uses Test

To assess divergent thinking, we used the AUT. 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 creativity of the responses. In order to assess creativity, four independent judges rated the creativity of each response on a scale of 1-5. Responses were shuffled and the judges were blind

as to which responses were generated by a given participant. The judges achieved good inter-rater reliability (Cronbach's $\alpha > 0.80$). The average number of responses generated was 10.2 ($SD = 5.2$), and the average creativity score was 2 ($SD = .42$). The total AUT scores ($M = 19.7$, $SD = 10.5$) were calculated for each participant by multiplying the creativity scores by the fluency scores.

Memory Task Stimuli

Stimuli were 80 photographs of real-world scenes. All scenes were presented in color at a resolution of 800x600 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, and a single type of target object was used for each category. The 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. 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 (Figure 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).

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 night stands; and in living rooms, the coffee mugs were on coffee tables. 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 in space). The spatial distributions of target locations were similar between scene conditions (for details, see Ramey et al., 2021).

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.

Fig. 1. Sample stimuli and procedure for memory task. 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. C) Closeup of the target object in the congruent scene (for visualization only; this was not part of the experiment). D) Closeup 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 10s. After clicking or after 10s, whichever occurred first, a green ring appeared around the target for 3s. F) The trial sequence in the test phase, which consisted of 80 scenes (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.

Questionnaires

Participants also completed questionnaires to assess other aspects of creativity. 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, we also had participants complete the International Cognitive Ability Resource (ICAR; Condon & Revelle, 2014).

Procedure

The experiment lasted approximately one hour and consisted of an Alternative Uses Test (AUT), followed by a memory task, and then a series of questionnaires. All procedures were approved by the university Institutional Review Board.

Memory task

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 given a break midway through each phase.

Study phase. Participants were told that they would be searching for and clicking on target objects and were asked to try to remember the scene and object locations for a later memory test. During the study phase, participants were presented with 60 unique scenes that

were each repeated 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 (Figure 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 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 recognition memory response scale appeared and participants were given time as needed to respond.

Memory strength 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 a “sure 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 event 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 800x600px 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. Specifically, memory 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. To do this, we also 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 therefore 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 at study, 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 schema 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 (i.e., high-confidence misses), but without any potential contribution of unconscious memory. To assess effects of unconscious memory, we compared target distance between scenes that were old but forgotten (i.e., "I'm sure it's new" responses), and scenes that were truly new.

Statistical Analysis

All statistical analyses besides those using new scenes 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. 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. For analyses using new scenes, standard linear regression was used because the unconscious effects were calculated between subjects (i.e., comparing performance between subjects who saw a given scene as a new scene and those who saw it as an old scene). Effect sizes were calculated as a standardized regression coefficient (β) for continuous variables, and Cohen's d for categorical variables.

Results

First, to confirm that the manipulations had the intended effect, we examined the overall effects of episodic memory and semantic knowledge on spatial accuracy. As expected, participants' target distance in old scenes was reduced with increasing episodic memory strength, $\beta = -.31$, $t(9920) = -34.61$, $p < .0001$, and target distance was also lower in congruent than incongruent scenes, $t(15294) = -15.52$, $p < .0001$, $d = -.25$ (Figure 2). Moreover, recollection, familiarity strength, and unconscious memory each reduced target distance, $ps < .0001$. Thus, both schema knowledge and episodic memory separately improved spatial accuracy.

Figure 2. Overall effects of episodic memory and schema knowledge on spatial accuracy. 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 least-squares 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.

We then separately examined each episodic memory process and their interactions with schema congruency. We found that, in line with prior work (Ramey et al., 2021), recollection suppressed schema effects in the sample overall (Figure 2). That is, when scenes were recollected, there was no significant effect of schema congruency on target distance, $t(4188)=1.845$, $p=.07$, $d=.057$, such that schema information no longer influenced spatial accuracy. However, divergent thinking modulated this effect: total AUT score interacted with schema congruency to influence target distance in recollected scenes, $t(4707)=2.46$, $p=.014$, $d=.072$ (Figure 3). Specifically, higher divergent thinking scores predicted increased schema congruency effects within recollected scenes. Importantly, congruency effects were increased in a way that improved performance in highly divergent thinkers: Within recollected scenes, AUT score 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, $t(172)=-.49$, $p=.62$, $d=-.08$. Thus, when highly divergent thinkers recollected scenes, their spatial accuracy was more influenced by schema knowledge in a way that improved performance.

Figure 3. Spatial accuracy within recollected scenes, by congruency and divergent thinking performance. Note that divergent thinking was treated as continuous for all analyses, but was dichotomized for illustration to facilitate comparison with the effects in Figure 2. The least-squares means derived from a linear regression are plotted, and the error bars represent the standard error of these estimated means from the model.

Next, we examined how divergent thinking related to the effect of recollection on spatial accuracy overall, irrespective of schema effects. We found that the difference in target distance between recollection and high-confidence familiarity—that is, familiarity that was matched in overall memory strength to recollection—was larger when divergent thinking scores were higher, $t(6525)=-2.25$, $p=.025$, $d=-.056$. This indicates that in highly divergent thinkers, recollection had a stronger beneficial impact on overall performance.

To probe effects of familiarity strength, we examined the linear gradient of familiarity responses from “sure new” to “sure old.” As in prior work (Ramey et al., 2021), the effects of schema congruency on spatial accuracy were reduced by familiarity such that as familiarity strength increased, schema congruency effects decreased, $\beta=-.16$, $t(7000)=-7.84$, $p<.0001$. AUT score was not significantly related to differences in how familiarity strength influenced spatial

accuracy overall, $\beta=.01$, $t(4588)=.87$, $p=.39$, nor in how familiarity strength interacted with schema congruency effects, $\beta=.01$, $t(6951)=.73$, $p=.47$. Thus, divergent thinking ability was not related to differences in familiarity-based memory.

Figure 4. Unconscious memory effects on spatial accuracy, by congruency and divergent thinking performance. Given that participants were highly confident that they had not seen these old scenes (i.e., gave “I’m sure it’s new” responses), differences in spatial accuracy between new scenes and these forgotten old scenes were driven by unconscious memory. Note that divergent thinking was treated as continuous for all analyses, but was dichotomized for illustration to facilitate comparison with the effects in Figure 2. The least-squares means derived from a linear regression are plotted, and the error bars represent the standard error of these estimated means from the model.

Lastly, we examined how divergent thinking performance was related to unconscious memory by comparing performance between old scenes that participants had forgotten (“sure new” responses) and truly new scenes. We found that the effect of unconscious memory on target distance was stronger with increasing AUT scores, $t(2786)=-2.47$, $p=.014$, $d=-.093$. This indicates that the beneficial effects of unconscious memory on spatial accuracy were stronger when participants had higher divergent thinking scores. Moreover, while unconscious memory

reduced the size of schema effects in participants overall, $t(4625)=-2.88$, $p=.004$, $d=-.085$, this effect was influenced by divergent thinking: When AUT scores were higher, the suppression of schema effects by unconscious memory was stronger, $t(4583)=-2.908$, $p=.004$, $d=-.086$ (Figure 4). Importantly, schema 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 modulated the interaction between unconscious memory and schema knowledge in a way that improved performance.

To assess which aspects of divergent thinking drove the effects outlined above, we re-ran the AUT score analyses separately for the number of responses generated (i.e., fluency) and the rater-determined creativity scores. We found that the results were driven by fluency of divergent thinking, such that all significant effects above were significant when fluency alone was used as the measure of divergent thinking, $ps<.05$. In contrast, the present memory effects were not related to the creativity of responses, $ps>.24$. This indicates that differences in the number of ideas participants generated were the primary driver of the divergent thinking effects outlined above.

We also assessed the specificity and robustness of these effects by examining whether they were related to other types of creativity, and whether they held when controlling for overall cognitive ability. First, we found that the differences in recollection were unique to divergent thinking: The interaction between recollection and schema knowledge, and the differences

between recollection and familiarity, were not significantly influenced by imagination ability, creative achievement, or mind wandering $ps > .07$. We also found that the unconscious effects were unique to divergent thinking, $ps > .08$; mind wandering, however, exhibited the opposite effect as divergent thinking on the interaction of unconscious memory with schema knowledge, $p = .023$. Furthermore, all divergent thinking effects reported above held when controlling for overall cognitive ability, $ps < .05$, indicating that the relationship between divergent thinking and memory was not driven by differences in overall cognitive ability, nor by how much effort participants were putting into the experimental tasks.

Discussion

In the present study, we found that divergent thinking ability was related to differences in how schema knowledge was combined 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 performed better on a divergent thinking task, they exhibited a stronger influence of recollection on spatial accuracy overall, and an increased use of schema information within recollected scenes in a way that benefitted performance. Moreover, we found that when participants performed better on the divergent thinking task, unconscious memory led to larger spatial accuracy benefits overall, and unconscious memory was more effective at preventing detrimental schema bias. In contrast to recollection and unconscious memory, we found no differences in familiarity-based memory overall, nor in how it was combined with schema knowledge, with respect to divergent thinking. These effects were not driven by differences in overall cognitive ability, and were unique to divergent thinking in that these memory differences were not observed with respect to other measures of creativity. The present results confirm and extend prior work indicating 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). In particular, our findings show that the *interaction* between semantic knowledge and episodic memory—rather than each simply operating in parallel—may be an important cognitive mechanism underpinning 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, Saporta, et al., 2015). Thus far, compelling evidence has been found for the role of semantic knowledge (Beaty et al., 2014, 2020; Benedek et al., 2017; He et al., 2020; Kenett et al., 2014), attention (Zabelina, O’Leary, et al., 2015; Zabelina, Saporta, et al., 2015), cognitive control (Benedek, Jauk, Sommer, et al., 2014; Zabelina & Ganis, 2018), working memory (Lee & Theriault, 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 indicating that episodic memory is also an important process underpinning 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—but our findings suggest that recollection and unconscious memory, but not familiarity, function differently in those with high divergent thinking ability. 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). Moreover, given our findings that the interaction between episodic memory processes and

semantic knowledge may be important for divergent thinking, future studies examining the interactions between the other cognitive processes outlined above, such as attention and working memory, may be a particularly useful avenue for characterizing the cognitive mechanisms supporting divergent thinking.

The present findings of modulation of recollection and unconscious memory by divergent thinking ability, both overall and with respect to interactions with semantic knowledge, are 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, familiarity is known to rely on other medial temporal lobe regions, and there is increasing evidence that unconscious memory for relational information may rely on the hippocampus as well (Eichenbaum et al., 2007; Hannula & Greene, 2012). Our findings suggest that divergent thinking ability may be related to differences in how hippocampus-based memory is combined with schema knowledge to influence behavior: In each of the presently observed effects, higher divergent thinking performance predicted improved outcomes of combining episodic memory with schema knowledge, such that spatial accuracy was enhanced. When scenes were recollected, highly divergent thinkers incorporated schema information such that performance was improved in schema-congruent scenes, but unaffected in incongruent scenes. When scenes were unconsciously remembered, on the other hand, highly divergent thinkers were spared from detrimental effects of schema bias; that is, unconscious memory led to larger improvements in spatial accuracy within incongruent scenes when divergent thinking scores were higher. Together, these results suggest that divergent thinking ability is underpinned in part by the ability to flexibly combine hippocampus-based memory with semantic knowledge to optimize

performance—whether it involves amplifying schema knowledge when it is useful for performance, or inhibiting schema knowledge when it is detrimental to performance.

The fact that the present effects were limited to divergent thinking, such that they were not found in other aspects of creativity, is in line with prior findings that different types of creativity are supported by unique cognitive mechanisms. For example, whereas overall creative achievement is often associated with poorer attentional control, divergent thinking ability is related to improved attentional control (Zabelina, O’Leary, et al., 2015; Zabelina, Saporta, et al., 2015; Zabelina & Ganis, 2018). This is thought to reflect that the ability to quickly generate alternative uses, as in divergent thinking, requires an improved ability to filter out irrelevant information, whereas real-world creative achievement may instead benefit from a “leaky” attentional filter to facilitate the formation of remote associations and therefore creative thought (Zabelina, Saporta, et al., 2015). In line with this, in the present study we found that creative achievement was marginally related to the *opposite* unconscious memory effect as was obtained in divergent thinking ($p=.08$), such that higher creative achievement was related to a reduced ability of unconscious memory to prevent detrimental schema bias. Thus, creative achievement was related to impaired performance as a result of detrimental schema bias “leaking” into spatial memory decisions, whereas divergent thinking was related to the opposite effect—further supporting the idea that divergent thinking and creative achievement are related to distinct cognitive mechanisms.

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, these cognitive processes—in particular,

semantic knowledge and episodic memory—also interact with each other in important ways to facilitate divergent thinking.

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