Fanning Creative Thought: Semantic Richness Impacts Divergent Thinking

Roger E. Beaty (rebeaty@psu.edu)
Department of Psychology, Pennsylvania State University
University Park, PA 16802 USA
Yoed N. Kenett (yoedk@sas.upenn.edu)
Department of Psychology, University of Pennsylvania
Philadelphia, PA 19104 USA
Richard W. Hass (Richard.Hass@jefferson.edu)
Department of Psychology, Thomas Jefferson University
Philadelphia, PA 19144 USA

Abstract

Creative thinking has long been associated with spreading of activation through concepts within semantic networks. Here we examine one potential influence on spreading activation known as the *fan effect*: increasing concept knowledge leads to increasing interference from related concepts. We tested whether cue association size—an index of semantic richness reflecting the average number of elements associated with a concept—impacts the quantity and quality of responses generated during the alternate uses task (AUT). We hypothesized that low-association AUT cues should benefit quality at the cost of quantity because such cues are embedded within a semantic network with fewer conceptual elements, thus yielding lesser interference from closely-related concepts. This hypothesis was confirmed in Study 1. Study 2 replicated the effect and found an interaction with fluid intelligence, indicating that cognitive control can overcome constraints of semantic knowledge. The findings thus highlight costs and benefits of semantic knowledge for creative cognition.

Keywords: Divergent Thinking; Fan Effect; Fluid Intelligence; Semantic Memory

Introduction

Divergent thinking (DT) is considered a crucial aspect of creative thinking (Runco & Acar, 2012). DT involves generating novel and appropriate responses to open-ended idea generation tasks. However, the basic cognitive processes involved in DT such as memory retrieval are far from understood (Volle, 2018). Recent research highlights both benefits and costs of semantic memory retrieval for creative thought (Beaty, Christensen, Benedek, Silvia, & Schacter, 2017; Hass, 2017a, 2017b; Kenett, 2019). Here, we borrow a classic experimental paradigm from cognitive science research on semantic memory—the fan effect (Anderson, 1974)—to further characterize the impact of semantic memory structure on creative idea generation.

A fan effect is an increase in response time (or error rates) on a recognition test with an increase in the number of associations with a concept in a memory probe (Anderson, 1974). According to Anderson and Reder (1999), the associations among concepts cause interference (i.e., the more association links fanning from a concept node, the greater the interference). Such interference occurs at retrieval (Anderson & Reder, 1999). Thus, during divergent thinking, the fan size of the target cue may relate to interference in retrieving creative responses. This hypothesis fits strongly with the associative theory of creativity.

According to the associative theory of creative thinking, creativity involves the connection of weakly related, remote concepts into novel and applicable concepts (Mednick, 1962). The farther apart the concepts are in semantic space, the more creative the new combination will be. For this new combination to be applicable (i.e., to make sense) a broad body of knowledge is required. While this theory is still debated, the importance of associative abilities in creative processing has been demonstrated (Benedek, Könen, & Neubauer, 2012). Furthermore, recent computational studies have provided further support for how individual differences in creative ability relates to differences in semantic memory structure (Kenett, 2019; Kenett & Faust, 2019).

However, more recent theories have argued that creative thinking is more broadly related to an interaction between semantic memory structure and cognitive control processes that facilitate guided search throughout memory. For example, Beaty and Silvia (2012) examined how fluid intelligence (*Gf*) relates to the serial order effect – the tendency for ideas to become increasingly more original over time during a DT task (Christensen, Guilford, & Wilson, 1957; Hass & Beaty, 2018). The authors found that participants scoring high on *Gf* showed less of a serial-order effect. That is, high *Gf* scores were associated with greater originality earlier in participants' response. Thus, the authors argue for an executive control process operating on semantic memory that facilitates avoidance of high-frequency concepts (i.e., low-originality). Hass (2017b) applied computational approaches to demonstrate that the semantic similarity of participants' DT responses non-linearly decreases as a function of response order. Furthermore, this study found that the semantic similarity of initial DT responses was lower for participants with higher *Gf* scores.

In the current series of studies, we present results from an ongoing project, where we examine for the first time the role of fan size on DT responses. As the fan effect is considered to be related to activation of multiple associations to a

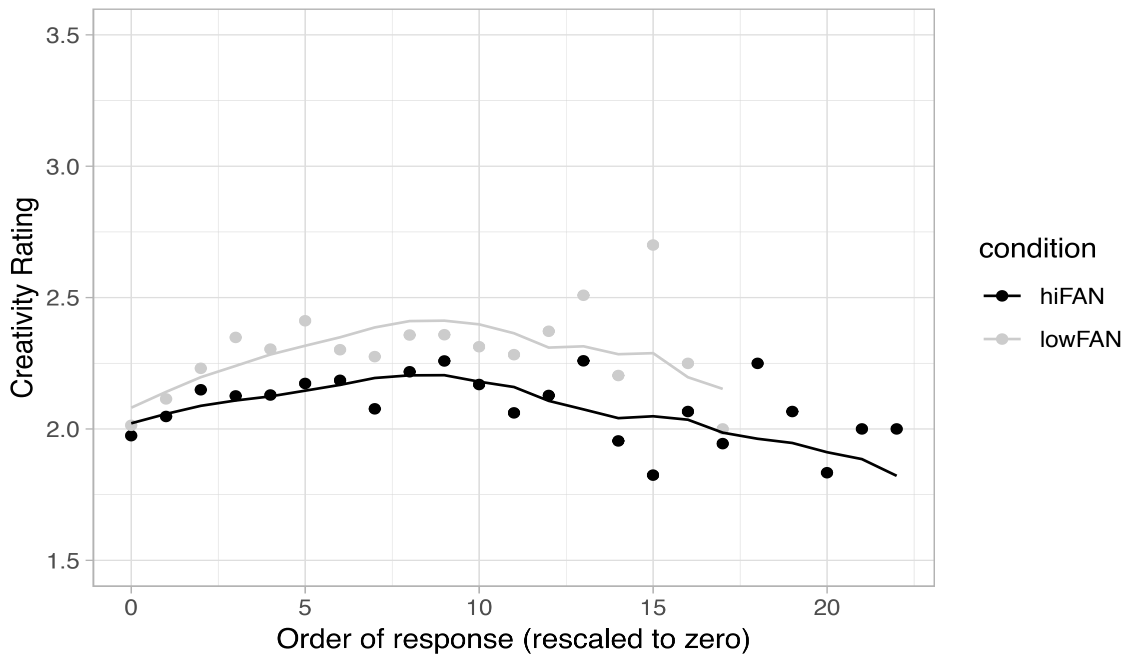

Fig. 1: Average creativity rating as a function of response order. The first response was rescaled to zero for the purpose of growth modeling. Lines represent fitted values for each condition based on the multilevel growth model.

concept that leads to interference, we predict that high-fan cues will lead to a higher number of DT responses but lower overall originality of these responses. Furthermore, we predict that fan size will interact with the serial order effect (Study 1) and with individual differences in *Gf* (Study 2).

Study 1

In Study 1, we sought to test for the existence of a fan effect in the context of performance on the Alternate Uses Task (AUT), a widely used assessment of DT (Runco & Acar, 2012). To this end, we assessed whether the quantity and creative quality of DT responses varied as a function of AUT cue association set size. We selected cue words for the AUT (i.e., common objects) with low- and high-fan size based on free association norms (Nelson, McEvoy, & Schreiber, 2004). Because high-fan cues are presumably embedded within denser semantic networks of highly-related concepts compared to low-fan cues, we hypothesized that participants would generate more AUT responses (i.e., higher fluency) but that this performance benefit would come at the cost of creative quality (i.e., lower originality) due to interference from salient concepts.

Participants

Fifty-five participants were recruited for the study via Amazon Mechanical Turk (AMT; Buhrmester, Kwang, & Gosling, 2011). Participants were offered $4.00 compensation for completion of all 10 tasks. No participants' work was rejected (i.e., all 55 workers were paid), however, a pre-analysis screening procedure identified 14 participants that failed to respond to all 10 cues and 1 participant that provided clearly random responses, and thus did not follow directions. The final sample size for analysis was 40 (30 female) with an average age of 38.1 years (SD = 12.07). A large majority of the sample identified as White/Caucasian (92.5%) with the remaining 7.5% identifying as either African American or "other". This study was approved by Jefferson University institutional review board.

Materials

Stimuli. We constructed low- and high-fan cues to be used in the DT task. Low- and high-fan cues were selected from the University of South Florida free association norms database, that includes norms for 5,000 cue words (Nelson et al., 2004). Importantly, for each of these cue words, the database lists the number and types of different associative responses that were generated to these cue words. The number of associative responses to a cue word was used as a proxy of fan size of the cue word (i.e., cue set size). Out of the 5,000 cue words, cue words of concrete objects that can be used in a DT task were manually selected. Finally, a list of five low-fan (clock, fork, lamp, lens, pen) and five high-fan (soap, rope, stick, marble, balloon) cues were selected. These cue words were matched on key linguistic variables: *frequency* (low-fan $M = 16.4$, $SD = 3.29$; high-fan $M = 21.3$, $SD = 10.97$; $t(8) = 1.00$, $p = .35$) and *concreteness* (low-fan $M = 5.88$, $SD = .67$; high-fan $M = 6.09$, $SD = .23$; $t(8) = .66$, $p = .53$). Critically, the average set size of the high-fan cues ($M = 22$, $SD = 1.22$) was significantly greater than the average set size of the low-fan cues ($M = 6.6$, $SD = 1.51$; $t(8) = 17.67$, $p < .001$).

Divergent thinking task. For each of the ten cue words (low- and high-fan), participants had three minutes to generate as many alternative uses as possible. Two main measures were computed from participants DT performance: originality and fluency. For each response, *originality* was defined as the average of the originality ratings across independent raters for that response and *fluency* was defined as the sum of responses; we also logged *inter-response time* (the time between the first key strokes of successive responses) and the *order* of entry of each response. Participant-level variables were fluency and composite originality score (i.e., the average of the originality scores per person per prompt).

Procedure

A custom web application was created for administering the experimental tasks (Hass & Beaty, 2018). The interface consisted of an instructions page and a response-collection interface. The instructions page appeared before both blocks of trials (low- and high-fan) and, after reading instructions, participants proceeded to the tasks using a navigation button. The task interface appeared in an 800x600 pixel window and consisted of a text-display, which contained the object prompt for that trial and a text-entry field. The text-entry field allowed participants to edit responses prior to entering them and moving on to the next. Javascript code saved the first key press per response, the time at which the participant entered the response (by pressing ENTER or RETURN), and the text of the response itself. When ENTER was pressed, the text-field was cleared, and participants were not allowed to view previous responses.

First, participants provided consent to participate in the experiment. Following consent, participants were presented with an overall description of their task: that they would be prompted to generate ideas about specific prompts, along with some information about how long it would take, and that they should be ready to type. Participants then completed a practice trial to become acclimated to the typed entry interface which involved typing the names of colors that they knew for 30 seconds. Upon completion of practice, the first set of experimental trials started. They were informed that there would be five trials, each with a different object, and each lasting 3 minutes each. They then pressed a navigation button to continue. The order of trials within blocks and block presentation were randomized, and participants had a short break between blocks. Finally, participants completed a short demographic survey.

Results

Participants' responses were rated for originality on a 5-point scale designed for cognitive studies of DT (Hass, Rivera, & Silvia, 2018) by two research assistants and one AMT worker not involved in the experiment. Inter-rater reliability (ICC(2,3)) ranged from fair to good across the 10 cues (M = .47, SD = .15).

Participants generated a significantly higher number of responses to high-fan prompts (M = 9.17, SD = 3.42) than to low-fan cues (M = 8.1, SD = 3.1), $t(39) = 3.84$, $p < .001$). Furthermore, high-fan responses were rated significantly less original (M = 2.67, SD = 0.26) compared with low-fan responses (M = 3.03, SD = 0.26), $t(39) = 6.47$, $p < .001$. Together, these findings suggest that while high-fan cues afford more associative links (i.e., increased fluency), the effect may interfere with generating original responses (i.e., decreased originality) to them.

To investigate temporal effects of the fan manipulation, two response-level analyses were performed. First, inter-response times (IRTs) were compared across the two conditions with a mixed-effects regression model. In order to conform to model assumptions (namely normally distributed residuals), IRTs were log-transformed and regressed on 1) a fixed-effect of condition (low- vs. high-fan), 2) a random effect of participant, and 3) a random effect of cue. Though mean IRTs were shorter in the high-fan condition (M = 14.50s, SD = 13.99s) compared with the low-fan condition (M = 16.14s, SD = 16.63s), the fixed effect in the log-IRT model was not significant (b = .0004, p = 0.55).

Next, the relationship between response order and creativity rating was examined with a mixed-effects model. Prior results have illustrated a curvilinear relationship between serial order and creativity (Hass & Beaty, 2018) so linear and quadratic serial order terms were entered into the model. Interactions between condition (low- vs. high-fan) and both of the serial order terms were also modeled, along with random effects of participant and cue. There were significant linear (b = 0.039, $p < .001$) and quadratic trends (b = -0.016, p = .02), but the overall difference between low- and high-fan originality was not preserved in this model (b = 0.062, p = .61). Additionally, there was no difference in either the linear (b = 0.025, p = 0.15) or quadratic slopes (b = -0.016, p = .23) across the fan conditions (Fig. 1).

Discussion

The associative theory of creativity implicates spreading activation across concepts within semantic networks to generate novel ideas (Mednick, 1962). However, little is yet known about the benefits—and potential costs—of semantic memory in creative cognition. Here, we identify such benefits and costs of semantic knowledge to performance on a divergent thinking task. Participants generated more responses during the AUT when using high-fan cues compared to low-fan cues, suggesting that greater semantic content benefits ideational fluency. This benefit, however, came at the cost of originality: participants generated ideas that were rated as less original in the high-fan condition. This finding is consistent with the notion that salient conceptual information (e.g., high-fan associations) can constrain creative thought by acting as a source of interference that must be inhibited to establish more remote conceptual combinations (Beaty et al., 2017; Chrysikou, 2019). In sum, the results of Study 1 suggest that the structure and content of semantic knowledge impacts the quality and quantity of ideas generated during divergent thinking.

Study 2

In Study 2, we sought to replicate and extend the findings from Study 1. Specifically, we employed the same

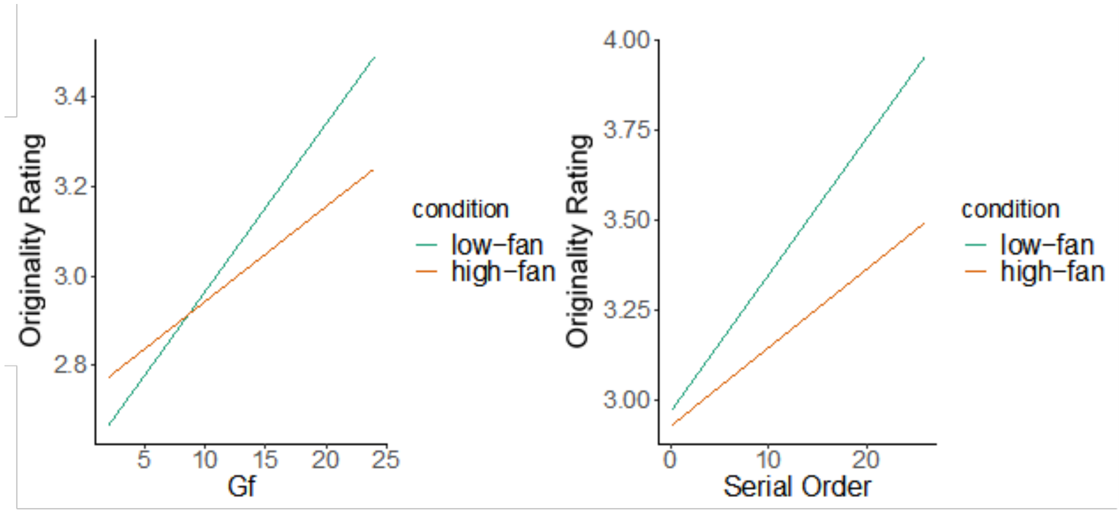

Fig. 2: Interaction effects between serial order and fan effect (left) and Gf and fan effect (right) on participant's originality ratings of their DT responses.

experimental paradigm—varying cue set size across AUT i tems—and further examined potential interactions with fluid intelligence (*Gf*), an individual difference variable with established links to divergent thinking (Beaty & Silvia, 2012). Although *Gf* has been shown to predict the creative quality of DT respons es, the cognitive contribution of *Gf* to creative performance remains largely uncharacterized. One possibility is that *Gf* supports inhibitory control processes, consistent with its strong association with cognitive control (Kane, Hambrick, & Conway, 2005) Thus, *Gf* may be more relevant for high-fan idea generation via the inhibition of salient conceptual knowledge (Beaty & Silvia, 2012). On the other hand, *Gf* may support low-fan idea generation by facilitating spreading activation within a relatively sparse semantic space. In addition to examining the role of *Gf*, we further probed temporal dynamics of the fan effect as a function of cue set size.

Participants

One hundred thirteen participants (50 females) were recruited from AMT. The average age of participants was 37.71 years (SD = 10.49). All participants were fluent in English and the majority (58%) were Caucasian. African Americans comprised 11% of the sample, Asian Americans comprised 5% of the sample, Hispanic Americans comprised 8% of the sample, Native Americans comprised 14% of the sample, while the remainder identified ethnicity as "other". Participants received $5.50 for their participation. Thirty-three participants were excluded from the analysis for failure to successfully complete all tasks or providing nonsensical answers to open-ended questions. The final sample size for the current analysis was $N = 83$. This study was approved by Jefferson University institutional review board.

Materials

Stimuli. The stimuli used in Study 2 were identical to those used in Study 1.

Divergent Thinking. The DT task used in Study 2 was identical to that used in Study 1.

Fluid Intelligence. Based on Kenett et al. (2016), *Gf* was assessed via three separate tasks: 1) The series task from the Culture Fair Intelligence Test (CFIT) which involves choosing an image that correctly completes a series of images (13 items, 3 min); 2) A letter-sets task, which presents a series of four-letter combinations and requires people to determine which set does not follow a rule governing the other four (16 items, 4 min); and 3) A number-series task in which participants complete a sequence of numbers by discovering a guiding rule (15 items, 5 min). To compute a general *Gf* score, we used principal component analysis. This composite *Gf* score was constructed as the sum of the multiplication of each independent *Gf* score by its weight of the first unrotated principal component (Kenett et al., 2016).

Procedure

The DT task was run similarly as in Study 1 and the *Gf* tasks were run via Qualtrics (www.qualtrics.com). Upon providing electronic consent, participants were presented with an overall description of their tasks: that they would be prompted to generate ideas about specific prompts for approximately 30 minutes, and they would then complete some IQ-based tasks for another 20 to 30 minutes. Participants then completed a practice idea-generation trial to become acclimated to the typed entry interface (naming colors). Upon completion of practice, the first set of experimental trials began. The order of trials within blocks and block presentation were randomized, and participants had a short break between blocks. Finally, participants completed a short demographic survey.

Results

Three raters scored responses for originality using the same scale used in Study 1 (Hass et al., 2018). Inter-rater reliability, assessed with interclass coefficients ICC(2,3), was generally high across the 10 cues ($M = .68$, $SD = .12$).

Analyzing the fluency and originality of participants responses, our results replicate the findings of Study 1: Participants generated a significantly higher number of responses to high-fan cues ($M = 7.56$, $SD = 3.82$) than to low-fan cues ($M = 6.33$, $SD = 3.04$), $t(82) = -4.64$, $p < .001$. Furthermore, high-fan responses were rated significantly less original ($M = 3.04$, $SD = .33$) compared with low-fan responses ($M = 3.12$, $SD = .44$),, $t(82) = 2.14$, $p < .035$. Together, these findings suggest that while high-fan concepts afford more associative links, these links may interfere with establishing more remote conceptual combinations.

Next, the relationship between response order and creativity rating was examined via a mixed-effects model. In our full model, *Gf*, fan, and serial order were assigned as independent measures, and the originality ratings as the dependent measure. Interactions between fan and *Gf*, interaction between fan and serial order, and interaction between *Gf* and serial order terms were also modeled, along with random effects of participant and cue (Table 1). We first compared this model to a model that only included the random effects and found that this model improved the fit to originality ratings, χ^2 (6, N = 83) = 105.52, $p < .001$. Specifically, we find a significant positive relation between each of the three main variables (*Gf*, Fan, and Order) on participant's originality scores. Thus, we replicate and strengthen the results found in Study 1, and replicate previous findings on the effect of *Gf* on DT (Beaty & Silvia, 2012). As for the effect of the interaction terms, we found significant negative relations between both interaction terms (*Gf**Fan and order*fan) on participant's originality scores (Fig. 2). However, due to high collinearity between the serial order variable and the interaction of *Gf* and serial order variable ($r = -.71$), the interaction effect of serial order and *Gf* was not significantly related to originality scores in this model.

Table 1: Linear mixed effect model of originality

Fixed Effects	*B*	SE	*p*
Intercept	2.28	0.18	< .001
Gf	0.05	0.01	< .001
Fan	0.19	0.10	.05
Order	0.05	0.01	< .001
*Gf**Fan	-0.02	0.00	< .001
Order*Fan	-0.02	0.01	< .001
Random Effects	Name	Variance	SD
Participant	Intercept	0.09	0.30
Cue	Intercept	0.01	0.09
Residual		0.65	0.80

Full model: Originality ~ *Gf* + Fan + Order + *Gf**Fan + Order*Fan + *Gf**Order (1|participant) + (1|cue)

Discussion

Study 2 replicated the findings of Study 1 and extended them by examining individual differences in *Gf* (Beaty & Silvia, 2012). As in Study 1, we found that, compared to low-fan cues, high-fan cues yielded increased fluency but decreased originality. Study 2 further examined temporal dynamics of this fan effect. Specifically, we replicated the serial order effect in divergent thinking—the tendency of idea originality to increase over time (Hass & Beaty, 2018)—and showed how this serial order effect interacted with both fan size and *Gf*. Although the 3-way interaction between serial order, fan size, and *Gf* was not significant, due to exceedingly high collinearity between these independent variables, we found that interaction effects of *Gf**Fan and Order*Fan explained significant variance in creativity ratings.

General Discussion

Divergent thinking tasks are widely used to assess creative thinking, but little is known about the basic cognitive processes underlying their performance. In two studies, we borrowed a classic experimental manipulation from cognitive research on semantic memory known as the fan effect (Anderson, 1974)—the tendency for increasing semantic associations to interfere with memory performance—and show that it similarly (but differentially) impacts the quality and quantity of divergent thinking responses. In Study 1, we found that although participants generated significantly more responses using high-fan cues compared to low-fan cues (i.e., increased fluency), these responses were rated as significantly less original. In Study 2, we replicated these findings and extended them by showing that the fan effect for originality varied as a function of individual differences in *Gf*: as *Gf* increased, so did originality ratings in the low-fan condition compared to the high-fan condition. Taken together, the results extend recent work on the dynamics of memory retrieval and cognitive control during creative idea generation (Benedek & Fink, 2019).

These findings inform a growing literature on the role of cognitive control in divergent thinking. Consistent with past work (Beaty & Silvia, 2012; Benedek, Jauk, Sommer, Arendasy, & Neubauer, 2014), Study 2 found that *Gf* predicted the creative quality of divergent thinking responses. Critically, we found that *Gf* interacted with the fan effect: higher-*Gf* benefited low-fan originality. From a semantic network perspective, the low-fan cues may be embedded in a less densely connected network, potentially blunting spreading activation to remote concepts due to less semantic scaffolding (Mednick, 1962). Thus, one possibility is that *Gf* compensates for such sparse semantic connectivity by driving search processes in a top-down fashion. In other words, when less is known about an object, cognitive control may facilitate strategic and deliberate conceptual combination.

On the other hand, one might predict *Gf* to benefit high-fan originality. Because the high-fan cues may be embedded within a relatively denser network of semantic associations—as reflected by higher ideational fluency in the high-fan condition across both studies—these associations may have induced interference due to high salience and semantic relatedness. Prior research suggests that salient concepts can disrupt idea generation by priming what is already known and thus not original (Beaty et al., 2017). Thus, cognitive control could benefit high-fan cues via inhibitory mechanisms, i.e., suppressing dominant responses and redirecting search processes (Beaty & Silvia, 2012). Notably, however, Study 2 assessed *Gf*—a proxy measure of general cognitive control which shows strong correlation with executive processes such as inhibitory control (Kane et al., 2005) Future work might resolve this question by examining the contribution of specific executive functions to idea generation under similar semantic constraints.

The present research has potential implications for understanding the role of semantic knowledge in creative cognition (Kenett & Faust, 2019). Across both studies, we found a dissociation between the quantity and quality of ideas as a function of fan size: more ideas are generated when more was "known" about an object—as indexed via semantic associations—but these ideas were deemed to be of less creative quality. An interesting direction for future research would be to explore the extent to which this effect extends beyond "domain-general" creative performance to specific creative domains. Another outstanding question concerns whether the organization of semantic knowledge can be optimized for creativity through learning. We suspect that high creative ability is characterized by extensive domain-relevant knowledge, and superior access to that knowledge, via its hierarchical organization and top-down retrieval.

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