A Fan Effect for Creative Thought:

Semantic Richness Facilitates Idea Quantity but Constrains Idea Quality

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Abstract

Creative thinking has long been associated with spreading of activation through concepts within semantic memory. Despite its theoretical importance, little is yet known about how semantic memory structure facilitates and constrains idea production. We examine one potential influence on spreading activation during divergent thinking known as the *fan effect*: increasing knowledge about a concept leads to increasing interference from conceptually related information. Specifically, we tested whether cue association size—an index of semantic richness reflecting the average number of elements associated with a given concept—impacts the quantity (fluency) and quality (originality) of responses generated during the alternate uses task (AUT). We hypothesized that low-association AUT cues should benefit originality at the cost of fluency 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 three experiments. Furthermore, we found an interaction with individual differences in fluid intelligence in the low-association AUT cues, suggesting that constraints of sparse semantic knowledge can be overcome with top-down intervention. The findings indicate that semantic richness differentially impacts the quality and quantity of generated ideas, and that cognitive control processes can facilitate idea production when conceptual knowledge is limited.

Keywords: creativity, divergent thinking, fan effect, fluid intelligence, semantic memory

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Creativity theories have long emphasized the role of semantic memory for creative thought (Beaty & Schacter, 2018; Hass & Beaty, 2018; Kenett, 2018b; Kenett, Anaki, & Faust, 2014; Kenett et al., 2018; Mednick, 1962). Semantic memory stores facts, concepts, and general knowledge that can be retrieved and combined in new ways to facilitate creative thinking. According to the associative theory of creativity (Mednick, 1962), creative thinking is related to the ability to connect concepts in memory that are weakly related, or “far away” from each other, in a novel and appropriate way—analogous to the process of spreading of activation through concepts in semantic memory (Collins & Loftus, 1975). Thus, as the semantic “distance” between two concepts increases, so does the likelihood of the combined concept being deemed creative (Green, 2016; Kenett, 2018a, 2018b; Mednick, 1962).

Despite the theoretical relevance of semantic memory for creative thinking, little empirical work has examined its specific cognitive contributions to creative task performance (Benedek & Neubauer, 2013; Kenett & Faust, 2019), leaving open questions about how and when this memory system impacts creative thought processes (Beaty, Christensen, Benedek, Silvia, & Schacter, 2017; Kenett, 2018b). Although semantic memory is undoubtedly necessary for creative processes such as conceptual combination or imagination (Abraham, 2014; Abraham & Bubic, 2015), research has also documented constraints of semantic knowledge on creative performance such as functional fixedness—a biasing of attention to salient conceptual features that prevents cognitive flexibility (Chrysikou, Motyka, Nigro, Yang, & Thompson-Schill, 2016; Chrysikou & Weisberg, 2005). In the present research, we aim to shed further light on the benefits and costs of semantic memory to creative thought by examining a classic experimental finding in semantic memory research known as the *fan effect*—a tendency for increased concept knowledge to impact retrieval mechanisms (Anderson, 1974; Anderson & Reder, 1999).

Creative Thinking and Semantic Memory

The associative theory of creativity (Mednick, 1962) proposes that creative individuals have a richer and more flexible associative network than less creative individuals. According to this theory (Mednick, 1962), creative individuals are characterized by “flat” (more and broader associations to a given concept) instead of “steep” associational hierarchies (few, common associations to a given concept; but see Benedek & Neubauer, 2013). Thus, creative individuals may have more associative links between concepts in their semantic memory and can connect associative relations faster than less creative individuals, thereby facilitating more efficient search processes (Kenett, 2018b; Volle, 2018). Thus, when attempting to think creatively, the less creative individual is likely to become “stuck” on these dominant, common, associations whereas the more creative individual can overcome them and proceed to establishing more distant associations, via spreading activation (Kenett & Austerweil, 2016). Within this framework, semantically “close” concepts are considered less likely to be creative, whereas semantically “distant” concepts are often considered creative (Heinen & Johnson, 2018; Kenett, 2018a).

While still debated (Benedek & Neubauer, 2013), the associative theory of creativity has received recent empirical support from computational investigations of individual differences in creative thinking (Benedek et al., 2017; Christensen, Kenett, Cotter, Beaty, & Silvia, 2018; Kenett, Beaty, Silvia, Anaki, & Faust, 2016; Kenett et al., 2018). For example, Kenett and colleagues conducted a network analysis of free association data to compare the semantic network structure of high- and low-creative individuals—defined by performance on a battery of creative thinking tasks—and found that, compared to the low-creative group, the high creative group showed a more “flexible” network structure characterized by higher connectivity and lower overall distances between concepts in their semantic network (Kenett et al., 2014), likely permitting more efficient spreading activation processes to unfold. These findings have since been replicated and extended in other group-based analyses (Gray et al., 2019; Kenett et al., 2016; Kenett et al., 2018), as well as at the individual level, including a study that estimated semantic networks and examined how properties of individual’s semantic networks relate to creative performance (Benedek et al., 2017). A

similar network structure was also reported in a recent study of openness to experience—a personality trait linked to creative behavior and cognition (Christensen et al., 2018)—providing further support for the role of semantic memory in creativity (Kenett & Faust, 2019; Volle, 2018).

Cognitive Fixation and Executive Control

Despite growing empirical support for the associative theory of creativity, past work has demonstrated constraining effects of semantic memory on creative performance, including fixating on stereotypical object information (i.e., functional fixedness; Chrysikou et al., 2016; Chrysikou & Weisberg, 2005; Glucksberg & Weisberg, 1966), biasing idea generation with salient examples (Beaty et al., 2017; Chrysikou et al., 2016; Marsh, Landau, & Hicks, 1996; Smith, Ward, & Schumacher, 1993), and priming incorrect solutions on the remote associates test (Smith & Blankenship, 1991). These findings contribute to a growing literature on the role of cognitive control in creative thought (Beaty, Benedek, Silvia, & Schacter, 2016; Benedek, Jauk, Sommer, Arendasy, & Neubauer, 2014; Chrysikou, 2019; Nusbaum & Silvia, 2011). This work has highlighted the involvement of executive and strategic aspects of cognition required to manage and direct memory processes, including pre-potent response inhibition (Benedek et al., 2014), broad retrieval ability (Avitia & Kaufman, 2014; Silvia, Beaty, & Nusbaum, 2013), and category switching (Nusbaum & Silvia, 2011). The joint contributions of spreading activation (bottom-up) and cognitive control mechanisms (top-down) are consistent with dual-process models of creative cognition (Barr, Pennycook, Stolz, & Fugelsang, 2015; Kleinmintz, Ivancovsky, & Shamay-Tsoory, 2019; Sowden, Pringle, & Gabora, 2014; Volle, 2018). In general, dual processes theories posit that creative thinking involves a dynamic interaction between idea generation and idea evaluation, corresponding to memory retrieval and cognitive control processes, respectively; notably, the extent to which these processes operate in serial or parallel remains unclear (Sowden et al., 2014).

To characterize the cognitive dynamics of creative thinking, researchers have examined a temporal trend in idea production known as the serial order effect (Acar, Chen, & Cayirdag, 2018; Beaty, Silvia, Nusbaum, Jauk, & Benedek, 2014; Christensen, Guilford, & Wilson, 1957; Hass & Beaty, 2018; Wang,

Hao, Ku, Grabner, & Fink, 2017). The serial order effect is the tendency for responses to a divergent thinking test to become less frequent and more original over time. This temporal trend has been explained within the associative theory of creativity: at the beginning of an idea generation task (e.g., thinking of alternate uses for a common object), fluency is high because people typically begin by activating the rich semantic neighborhood surrounding the object cue, thus producing known uses for the object (Gilhooly, Fioratou, Anthony, & Wynn, 2007). Likewise, originality is high later in task because it takes time for spreading activation processes to unfold (i.e., to reach more distal concepts within a semantic network; (Collins & Loftus, 1975; Mednick, 1962). This temporal process, however, does not appear to be constant across individuals (cf. Rominger et al., 2019); for example, Beaty and Silvia (2012) examined individual differences in the serial order effect and found that it interacted with fluid intelligence (*Gf*): as *Gf* increased, the serial order effect for originality diminished (see also Hass, 2017). Time was thus less relevant for originality at higher levels of intelligence, suggesting that cognitive control may mitigate early sources of semantic interference.

The Present Research

Past research has shed light on the contribution of semantic memory to creative cognition. At the individual level, for example, a more “flexible” network structure has been shown to facilitate creative idea generation (Beaty et al., 2014; Benedek et al., 2017; Kenett, 2019; Kenett et al., 2014). On the other hand, the activation of salient conceptual knowledge can constrain creative thought (Beaty et al., 2017; Smith & Blankenship, 1991). Together, these findings indicate that the organization of and access to concepts in semantic memory plays a key role in how they are retrieved during creative task performance. This work thus raises a fundamental question for creativity research; namely, *how and when does semantic memory structure facilitate and constrain creative thought?*

In the present research, we sought to address this question by exploring a classic finding in semantic memory research known as the *fan effect*. A fan effect is a memory phenomenon whereby increasing knowledge about a concept (or cue) leads to an increase in reaction time and accuracy on recognition

memory tests (Anderson, 1974; Anderson & Reder, 1999; Radvansky, 1999). The fan effect stems from the activation of competing concepts in memory. In the original work, Anderson (1974) showed that increasing the presentation of to-be-remembered items (i.e., propositional phrases) over the course of an encoding phase slowed reaction time (RT) and impaired accuracy in a subsequent recognition test. This RT lag has been attributed to an exhaustive, serial search process through all items, whereas the accuracy deficit relates to the proportion of accumulated knowledge and associative strength between concepts (Anderson & Reder, 1999). To overcome such semantic interference, Radvansky (1999) proposed an inhibitory mechanism that functions to suppress highly related memory traces. This contention received support from individual differences research on working memory capacity (WMC: Bunting, Conway, & Heitz, 2004). Consistent with the theory of WMC as controlled/executive attention (Kane, Bleckley, Conway, & Engle, 2001), Bunting and colleagues (2004) found that high-WMC buffered against the fan effect: compared to low-WMC participants, high-WMC participants showed faster RT and more accurate recognition (but not learning; i.e., the groups took the same amount of time to learn materials) when studying a series of unrelated sentences with shared concepts (i.e., fans).

Considered in the context of the associative theory of creativity, the fan effect offers an interesting paradigm to further probe the role of semantic memory in creative cognition. Does more or less knowledge about a concept influence how one thinks creatively with that concept? On the one hand, the associative theory posits that greater semantic richness facilitates spreading activation via more associative elements and connections (Mednick, 1962); in other words, the semantic infrastructure afforded by extensive concept knowledge makes spreading activation easier. In the context of a divergent thinking task (or similar task involving idea generation), additional semantic knowledge may promote greater fluency as people “have more to say” about the topic/concept. On the other hand, an executive interpretation of the fan effect views semantic richness as potentially detrimental to originality, because most closely-connected concepts are highly conceptually related and thus not novel. Indeed, the fan effect is considered a source of interference in recognition memory paradigms (Anderson, 1974; Anderson & Reder, 1999). However, such semantic

interference can be overcome via suppressing its activation, as evidenced in studies of individual differences in executive control (Bunting et al., 2004).

We conducted a series of experiments to test for the existence and impact of a fan effect in divergent thinking. To this end, we selected cue words (i.e., common objects) for the classic Alternate Uses Task (AUT; Kaufman, Plucker, & Baer, 2008; Runco & Acar, 2012; Torrance, 1972) that varied in semantic richness, defined as the average number of associations linked to the cue words based on free association norms (Nelson, McEvoy, & Schreiber, 2004). We reasoned that, compared to low-association object cues, high-association cues may yield a greater number of ideas (i.e., higher fluency) because such cues are presumably embedded within more densely connected semantic networks. However, in light of past work on the interfering effects of close conceptual knowledge, we expected that this fluency benefit may come at the cost of originality as these ideas are likely to be less semantically distant (Study 1). At the same time, the relative sparseness of low-association cue neighborhoods may hinder spreading activation to distal concepts in the absence of a robust semantic infrastructure. To probe temporal dynamics of idea generation as a function of fan size, we tracked the serial order of response production (Study 2). We also examined whether people high in cognitive control ability may be more immune to potential fan effects (Study 3).

Study 1

In Study 1, we aimed to test for the existence of a fan effect in divergent thinking performance. To this end, we developed an experimental manipulation of cue type in the Alternative Uses Task (AUT), a commonly used assessment of divergent creative thinking (Kaufman et al., 2008; Runco & Acar, 2012). We identified AUT cues (i.e., common objects) that varied as a function of cue association set size—an index of semantic richness defined as the average number of free associations generated by participants in a widely used free association norms dataset (Nelson et al., 2004)—thus yielding high-association cues (i.e., “high-fan”) and low-association cues (i.e., “low-fan”). We hypothesized that, compared to the low-fan condition, participants would generate significantly more AUT responses in the high-fan condition due to increased semantic richness of items related to these cues. Furthermore, we hypothesized that this fluency

benefit would come at a cost of originality, such that participants would generate AUT responses rated as more original in the low-fan condition due to a decreased presence of salient and highly-conceptually related (i.e., unoriginal) concepts.

Method

Participants

Forty participants were recruited for the study via Amazon Mechanical Turk (AMT; Buhrmester, Kwang, & Gosling, 2011). Participants were offered \$3.00 compensation for completion of the entire study. No participants' work was rejected (i.e., all 40 participants were paid), however, a pre-analysis screening procedure identified 4 participants that failed to provide responses for all 10 cues and thus did not follow instructions. The final sample size for analysis was 36 participants (19 female) with an average age of 36.34 years ($SD = 11.71$).

Materials

Stimuli. We began by constructing a list of low- and high-fan cues for the AUT. Low- and high-fan cues were selected from the University of South Florida Free Association Norms database, which includes norms for 5,018 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). Of the 5,018 cue words, we manually selected cue words of concrete objects that can be used in a DT task. Finally, a list of five low-fan (clock, fork, lamp, lens, pen) and five high-fan (soap, rope, stick, marble, balloon) cues were retained. These cue words were matched on key linguistic variables: *frequency* (high-fan $M = 21.4$, $SD = 10.97$; low-fan $M = 16.4$, $SD = 3.29$; $t(8) = 1.00$, $p = .35$) and *concreteness* (high-fan $M = 6.09$, $SD = .23$; low-fan $M = 5.88$, $SD = .67$; $t(8) = .66$, $p = .53$). 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 two minutes to generate as many alternate uses as possible. Two main measures were computed from participants' AUT performance: originality (i.e., average subjective rating) and fluency (i.e., sum of responses). Originality was rated on a 5-point scale designed for cognitive studies of divergent thinking (Hass, Rivera, & Silvia, 2018).

Procedure

Divergent thinking tasks were administered online via Qualtrics (www.qualtrics.com). High-fan cue trials ($n = 5$) were completed in one block and low-fan cue trials ($n = 5$) were completed in a separate block; the order of the blocks was counterbalanced across participants. The Qualtrics interface consisted of an instructions page and a response-collection page. For each AUT trial, participants had two minutes to type as many alternate uses as possible into textboxes presented on the response-collection page. Participants were given a short break between blocks. Following completion of the AUT blocks, participants completed a short demographic survey.

Results

Participants' AUT responses were rated for originality on a 5-point Likert scale designed for cognitive studies of DT (Hass et al., 2018) by three AMT participants not involved in the experiment (1 = very obvious/ordinary use, 5 = very imaginative/recontextualized use; cf., Hass & Beaty, 2018). Inter-rater reliability was assessed with interclass coefficients ICC(2,3), and was generally high across the 10 cues ($M = .61$, $SD = .11$).

To test whether DT performance varied as a function of fan size, we contrasted fluency and originality of AUT responses across the low- and high-fan conditions by computing paired t -test analyses on the means. Regarding fluency, participants generated significantly more responses in the high-fan condition ($M = 5.93$, $SD = 2.3$) compared to the low-fan condition ($M = 5.26$, $SD = 1.85$; $t(35) = 4.13$, $p < .001$). Regarding originality, participants generated significantly less original responses in the high-fan condition ($M = 2.50$, $SD = .30$) compared to the low-fan condition ($M = 2.72$, $SD = .34$; $t(35) = -5.95$, $p < .001$).

.001). Thus, high-fan AUT items yielded higher fluency but lower originality when compared to low-fan AUT items.

Discussion

The associative theory of creativity implicates spreading activation of concepts within semantic memory, but little is yet known about the benefits—and potential costs—of semantic memory in creative thinking. Study 1 identified one such benefit and cost of semantic knowledge to performance on a DT 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 creative 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).

Study 2

The goal of Study 1 was to obtain preliminary evidence for the existence of a fan effect in DT. In Study 2, we sought to replicate the fan effect in a larger sample of participants using a new online platform with greater experimental control than Study 1 (Hass & Beaty, 2018). This platform allowed us to further probe potential temporal dynamics of the fan effect. Specifically, we examined whether the fan effect interacted with the serial order effect—the tendency for AUT response originality to increase over time (Beaty & Silvia, 2012).

Method

Participants

Fifty-five participants were recruited for the study via AMT. We built on the sample size of Study 1 as a benchmark ($n = 40$) for replication and increased the sample size based on the availability of funds. Participants were offered \$4.00 US compensation for completion of the study. No participants' work was rejected (i.e., all 55 participants were paid), however, a pre-analysis screening procedure identified 14

participants that failed to provide responses for all 10 cue words and 1 participant that provided random responses and thus did not follow directions. The final sample size for analysis was 40 participants (30 female) with an average age of 38.1 years ($SD = 12.07$). This study was approved by Jefferson University's institutional review board.

Materials

Stimuli. The same stimuli used in Study 1 were used here (10 AUT cues; 5 low-fan, 5 high-fan).

Divergent thinking task. For each of the ten cue words (low- and high-fan), participants had three minutes to generate as many alternate uses as possible. Like Study 1, fluency and originality were computed for each participant. Furthermore, we also logged *inter-response time* (the time between the first key strokes of successive responses) and the *order* of entry of each response.

Using the tools created by the psiTurk project (Gureckis et al., 2016), a custom web application was employed for administering the experimental tasks (for details on the platform, see Hass & Beaty, 2018). Similar to Study 1, 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); after reading instructions, participants moved on to the tasks using a navigation button. The task interface consisted of a text-display, which contained the object prompt for that trial and a text-entry field. 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.

Procedure

Upon accepting the HIT on MTurk, the psiTurk tools generated the experimental environment. Following consent and instructions, participants completed a practice trial to acclimate 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. Participants were informed that there would be five trials, each with a different object, and each lasting 3 minutes. Low- and high-fan conditions were separated by another instruction page which simply reiterated the previous instructions and informed participants that they could take a short break. The order of blocks and cues within blocks was randomized. Following the

DT tasks, participants completed a short demographic questionnaire, including their level of engagement with the experiment.

Results

Data Preparation

Participants' responses were rated for originality on the same 5-point scale as Study 1 (Hass et al., 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 ($M = .47$, $SD = .15$).

Participant-level Fluency and Originality

We first attempted to replicate the results of Study 1, by assessing whether fluency and originality varied as a function of fan size. Regarding fluency, participants generated significantly more responses in the high-fan condition ($M = 9.17$, $SD = 3.42$) compared to the low-fan condition ($M = 8.10$, $SD = 3.10$; $t = 3.84$, $p < .001$). Regarding originality, participants generated significantly less original responses in the high-fan condition ($M = 2.67$, $SD = .26$) compared to the low-fan condition ($M = 3.03$, $SD = .26$ $t = 6.47$, $p < .001$). These results replicate the findings of Study 1 and suggest that a higher number of associative links afforded by high-fan cues may benefit fluency at the cost of originality, potentially due to increased interference from salient but semantically similar concepts. Note that mean fluency values were higher in this study compared to Study 1 due to longer trials (2 min vs. 3 min) for response-level analysis.

Response-level effects: IRT and Serial Order

To further investigate potential 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. 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 prompt. 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, we examined the relationship between response order and originality rating per cue with a mixed-effects model. Prior results have illustrated a curvilinear relationship between serial order and originality (Beaty & Silvia, 2012; Hass & Beaty, 2018) so linear and quadratic serial order terms were entered into the model. Interactions between condition (low- vs. high-fan) and both serial order terms were also modeled, along with random effects of participant and prompt. The full model results are presented in Table 1. There were significant linear ($b = 0.039, p < .001$) and quadratic trends ($b = -0.0016, p = .02$), 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 significant difference in either the linear ($b = 0.025, p = 0.15$) or quadratic slopes ($b = -0.016, p = .23$) across the fan types (Fig. 1).

Table 1: Quadratic mixed effect model of Originality in Study 2

Fixed Effects	<i>B</i>	SE	<i>p</i>
Intercept	2.03	0.09	< .001
Serial Order (Linear)	0.04	0.01	< .001
Serial Order (Quadratic)	-0.002	0.10	.02
Fan	0.06	0.12	.61
Linear-Order*Fan	0.03	0.02	.15
Quadratic-Order*Fan	-0.002	0.01	.23
Random Effects	Name	Variance	SD
Participant	Intercept	0.05	0.21
Cue	Intercept	0.03	0.17
Residual		0.46	0.68

Full model: Originality $\sim$ fan + (order - 1) + (order - 1)² + (order - 1)*fan + (order - 1)²*fan + (1|participant) + (1|cue)

Fig. 1: Average originality 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.

Discussion

The aim of Study 2 was to replicate the results of Study 1 in a larger sample and to examine the interaction between the serial order effect (Beaty & Silvia, 2012) and the fan effect. Study 2 replicated the results of Study 1: high-fan cues led to increased fluency at a cost of lower originality. While we found a main effect of serial order on response originality, in line with previous studies, we did not find a significant interaction between serial order and fan-effect. A potential cause for this null finding relates to the effect size: the mean originality of low-fan responses (shown in gray) is clearly higher for most responses after the 3rd response, but the effect is on the order of about a quarter of a point on the 5-point rating scale. However, when generating the first few low- or high-fan responses, originality seems to vary less. This pattern may be a function of the fact that there are far more data points per participant in these early phases of the experiment, or it may be that fan has more of an effect when participants have exhausted a few, potentially well-learned responses. When responses are aggregated at the level of participant, these order effects are seemingly eliminated, leading to an overall significant uptick in originality for low-fan responses.

Also, the design of the psiTurk interface in Study 2 followed a previously used laboratory version of the task implemented in Matlab where each cue word appeared after a 5-second pause between the responding sessions. That is, it is assumed that participants would pay attention to the cue words and that responding to each cue word would start at the beginning of the change in a cue word. Inspection of some of the first-RTs from Study 2 indicated that a minority of participants may have become distracted during the task and missed the start of cue words. To address this concern, the experimental interface was re-designed for Study 3 to wait for a spacebar-press from participants before presenting the next cue word.

Study 3

Studies 1 & 2 established a fan effect in DT. In Study 3, we sought to further replicate and extend this finding. Specifically, we employed the same experimental paradigm—varying cue set size across AUT items—and further examined potential interactions with fluid intelligence (*Gf*), an individual difference

variable with established links to DT (Beaty & Silvia, 2012). Although *Gf* has been shown to predict the creative quality of DT responses, the cognitive contribution of *Gf* to creative performance remains largely unknown. One possibility is that *Gf* supports inhibitory control processes, consistent with its strong association with executive 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 generation by facilitating spreading activation within a relatively sparse semantic neighborhood. In addition to examining the role of *Gf*, we further probed temporal dynamics of the fan effect (i.e., serial order) as a function of cue set size.

Method

Participants

One hundred thirteen participants (50 females) were recruited from AMT. Sample size was based on similar previous studies of divergent thinking and fluid intelligence (Beaty & Silvia, 2012; Benedek et al., 2017). The average age of participants was 37.71 years ($SD = 10.49$). Participants received \$5.50 for completion of the experiment. Thirty-three participants were excluded from the analysis due to failure to successfully complete all tasks or providing nonsensical answers to the open-ended questions. The final sample size for the current analysis was 83 participants (41 female, 1 prefer-not-to-answer) with an average age of 36.46 years ($SD = 9.80$). This study was approved by Jefferson University institutional review board.

Materials

Stimuli. The stimuli used in Study 3 were identical to those used in Study 1.

Divergent Thinking. The DT task used in Study 3 was identical to that used in Study 2. The software used to run the task was slightly modified to increase RT precision, i.e., a cue word was not displayed until the participant pressed the spacebar.

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, which presents a sequence of numbers and requires participants to discover a rule governing their change (15 items, 5 min). To compute a general composite *Gf* score, we used principal component analysis, by summing the multiplication of each independent *Gf* score by its weight of the first unrotated principal component (Kenett et al., 2016).

Procedure

The procedure was similar to Study 2 in that data were collected using a custom psiTurk interface. Participants completed the DT tasks first, and then psiTurk linked to the *Gf* tasks, which were hosted 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 cues for approximately 30 minutes, and they would then complete some cognitive 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 cues within blocks and block presentation were randomized, and participants had a short break between blocks. When the DT tasks were completed, participants were informed that the first half of the experiment was complete, and an iFrame within their browser displayed the start of the *Gf* tasks hosted on Qualtrics. In addition to the *Gf* tasks, participants completed a short demographic survey. When the survey completion page of Qualtrics appeared within the iFrame, psiTurk displayed the “submit” button, and participants submitted their work for approval. Most participants completed the entire experiment within 70 minutes.

Results

Three raters were trained to score responses for originality using the same 5-point originality scale used in Studies 1 and 2 (Hass et al., 2018). Inter-rater reliability was assessed with interclass coefficients ICC(2,3), and was generally high across the 10 cues (mean = .68, SD = .12).

Analyzing the fluency and originality of participants’ responses, the results replicated findings from Studies 1 and 2: 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 ($M = 3.12$, $SD = .44$), $t(82) = 2.14$, $p < .035$).

Next, the relationship between response order and originality 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 2).

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, $\chi^2(6, N = 83) = 105.52$, $p < .001$. Specifically, we found a significant positive relation between each of the three main variables (*Gf*, fan, and order) on participants' originality scores. Thus, we replicate and extend 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 participants' 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 2: Linear mixed effect model of Originality

Fixed Effects	<i>B</i>	SE	<i>p</i>
Intercept	2.28	0.18	< .001
<i>Gf</i>	0.05	0.01	< .001
Fan	0.19	0.10	.05
Order	0.05	0.01	< .001
<i>Gf</i> *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 $\sim Gf + fan + order + Gf*fan + order*fan + Gf*order$ (1|participant) + (1|cue)

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.

Discussion

Study 3 replicated the findings of Studies 1 & 2, and extended them by examining individual differences in *Gf* (Beaty & Silvia, 2012). As in Studies 1 & 2, we found that, compared to low-fan cues, high-fan AUT cues yielded increased fluency but decreased originality. Study 3 further examined temporal dynamics of this fan effect. Specifically, we replicated the serial order effect in DT—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 of *Gf**fan and Order*fan explained significant variance in originality ratings.

General Discussion

Divergent thinking tasks are widely used to assess creative thinking, but little is known about the basic cognitive processes underlying divergent thinking performance. In three 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 showed that it 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 AUT cues compared to low-fan cues (i.e., increased fluency), these responses were rated as significantly less creative (i.e., decreased originality). In Study 2, we replicated these results and also examined the effect of serial order (e.g., responses become more creative over time) and how it relates to the fan-effect. While we found an effect of serial order, similar to previous studies (Beaty & Silvia, 2012), we did not find an interaction between serial order and fan-effect. This lack of interaction may be due to additional cognitive processes, such as cognitive control (Volle, 2018), but such control processes were not assessed in this study. In Study 3, we replicated the findings of Studies 1 and 2, and extended them by assessing individual differences cognitive control (i.e., *Gf*). We found that the fan effect for originality varied as a function of *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 production (Benedek & Fink, 2019; Chrysikou, 2019; Volle, 2018).

These findings inform a growing literature on the role of cognitive control in DT. Consistent with past work (Beaty & Silvia, 2012; Benedek et al., 2014), Study 3 found that *Gf* predicted the originality quality of DT responses. Critically, we found that *Gf* interacted with the fan effect: higher-*Gf* benefited originality with low-fan cues. From a semantic network perspective, the low-fan cues may be embedded in a less densely connected semantic neighborhood, potentially blunting spreading activation to remote concepts due to less semantic scaffolding (Kenett, 2018b; 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 are likely embedded within a relatively denser neighborhood 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; Chrysikou et al., 2016). Thus, cognitive control could benefit high-fan cues via inhibitory mechanisms, i.e., suppressing dominant responses and redirecting search processes (Beatty & Silvia, 2012). Notably, however, Study 3 assessed *Gf*—a proxy measure of general intelligence 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.

More generally, our findings on a cost-benefit effect of fan size on DT responses extends previous findings on linguistic “neighborhood” (phonological, orthographic, semantic) effects (Luce & Pisoni, 1998; Mirman & Magnuson, 2008). For example, Mirman and Magnuson (2008) found opposing effects of semantic neighbors on word recognition: near neighbors inhibited word recognition, while distant neighbors facilitated word recognition. The authors argue that this opposing effect is due an attractor dynamic effect: near neighbors act as competing attractors that inhibit word recognition, while distant neighbors create a gradient that facilitates settling on the correct (recognized word) attractor (Mirman & Magnuson, 2008).

The present research has potential implications for understanding the role of semantic knowledge in creative cognition (Kenett, 2018b; Kenett & Faust, 2019). Across three 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.

Finally, it would also be of interest to examine the possible influences of episodic memory retrieval on some of the effects we have documented. Recent studies have shown that an episodic specificity

induction that biases reliance on episodic retrieval (for review, see Schacter & Madore, 2016) produces an increase in subsequent fluency (and flexibility) but not originality on the AUT (Madore, Addis, & Schacter, 2015; Madore, Thakral, Beaty, Addis, & Schacter, 2017). However, it is unknown whether or how inducing a reliance on episodic retrieval during the AUT would impact the fan effects or individual differences observed here. Such studies could help to further our understanding of how both semantic and episodic memory contribute to creative cognition.

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Conflict of Interest

The authors declare no conflict of interest.

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