Mem Cogn
DOI 10.3758/s13421-014-0428-8

The roles of associative and executive processes in creative cognition

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Abstract How does the mind produce creative ideas? Past research has pointed to important roles of both executive and associative processes in creative cognition. But such work has largely focused on the influence of one ability or the other—executive or associative—so the extent to which both abilities may jointly affect creative thought remains unclear. Using multivariate structural equation modeling, we conducted two studies to determine the relative influences of executive and associative processes in domain-general creative cognition (i.e., divergent thinking). Participants completed a series of verbal fluency tasks, and their responses were analyzed by means of latent semantic analysis (LSA) and scored for semantic distance as a measure of associative ability. Participants also completed several measures of executive function—including broad retrieval ability (Gr) and fluid intelligence (Gf). Across both studies, we found substantial effects of both associative and executive abilities: As the average semantic distance between verbal fluency responses and cues increased, so did the creative quality of divergent-thinking responses (Study 1 and Study 2). Moreover, the creative quality of divergent-thinking responses was predicted by the executive variables—Gr (Study 1) and Gf (Study 2). Importantly, the effects of semantic distance and the executive function variables remained robust in the same structural equation model predicting divergent thinking, suggesting unique contributions of both constructs. The present research extends recent applications of LSA in creativity research and provides support for the notion that both associative and executive processes underlie the production of novel ideas.

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Keywords Divergent thinking · Latent semantic analysis · Fluid intelligence · Verbal fluency

The psychology of creativity has been of interest for several decades (Christensen, Guilford, & Wilson, 1957; Mednick, 1962), yet the cognitive basis of creative thought remains poorly understood (Finke, Ward, & Smith, 1992; Weisberg, 2006). Several theories have been proposed to explain this seemingly elusive cognitive process. The associative theory, for example, suggests that creative ideas arise spontaneously in mind through a series of associative processes that unfold in semantic memory (Bowden, Jung-Beeman, Fleck, & Kounios, 2005; Mednick, 1962). Another contemporary theory of creativity—the controlled-attention theory—suggests that creative ideas arise from the ability to exert top-down control over attention and cognition (Beaty & Silvia, 2012, 2013; Gilhooly, Fioratou, Anthony, & Wynn, 2007; Nusbaum & Silvia, 2011). In the present research, we sought to determine the relative influences of associative and executive processes in divergent thinking, using several well-established measures of executive function and a novel approach to the assessment of associative abilities.

The associative theory of creativity

The *associative theory* of creativity is grounded in the seminal work of Mednick (1962). Mednick contended that creative ideas result from individual differences in associative hierarchies, or the underlying structure of semantic knowledge. Accordingly, people with steep associative hierarchies will produce high-frequency associations at the beginning of word association tasks (e.g., *table–chair*) and quickly exhaust their output; people with flat associative hierarchies, in contrast, will produce a consistent stream of remotely associated

Published online: 05 June 2014

concepts across the duration of such tasks. A flat associative hierarchy is thus hypothesized to benefit creative thought because a diffuse organization of knowledge should increase the likelihood of forming novel conceptual combinations.

One of the most commonly used measures of creative thinking is the remote associates task (RAT; Mednick, 1962). The RAT was developed to assess insight problem solving, or the spontaneous "aha!" experience that occurs when a solution to a problem suddenly pops into one's mind. RAT problems present a series of three seemingly unrelated words (e.g., *rat–blue–cottage*), and participants must produce a fourth word that conceptually unites the other three (e.g., *cheese*). According to associative theory, people with flat associative hierarchies should perform better on insight tasks because their semantic knowledge base is loosely structured and thus more apt to form remote associations. More recently, the notion that unconscious processes underlie insight has been reinforced by neuroimaging studies showing that brain activation prior to problem solution, and even prior to problem presentation, may predict RAT solutions by insight (Bowden et al., 2005; Kounios et al., 2006).

Past research has often used continuous word association tasks to assess the uncommonness of responses, and has related this measure of associative ability to performance on the RAT (Mednick, Mednick, & Jung, 1964; Olczak & Kaplan, 1969; Piers & Kirchner, 1971). For example, Mednick et al. found that high scores on the RAT were related to greater overall response fluency, consistent with predictions of the associative theory. Olcak and Kaplan, however, found that the uncommonness of later word association responses was unrelated to RAT performance, inconsistent with the notion that later responses should be more uncommon in high RAT performers (Mednick, 1962). The results of these studies may not be directly comparable, however, due to methodological differences and questions about whether performance on insight problems predicts real-world creativity (Beaty, Nusbaum, & Silvia, 2014; Mendelsohn, 1976; Weisberg, 2006; Worthen & Clark, 1971).

Recently, Benedek and Neubauer (2013) sought to overcome such limitations by administering a divergent-thinking task—a well-validated measure of creativity (Beaty, Smeekens, Silvia, Hodges, & Kane, 2013; Kaufman, Plucker, & Baer, 2008; Torrance, 1988)—and assessing the uncommonness of word association responses over time in high- and low-creative individuals. Benedek and Neubauer found that high-creative individuals showed greater associative uncommonness, but that this effect could be largely explained by differences in response fluency. Furthermore, high- and low-creative individuals showed the same trend of serially increasing uncommonness of responses, but this sequence was generated significantly faster by creative individuals, who were able to reach more remote responses. Benedek and Neubauer concluded that group differences in average associative uncommonness are due to more effective access to memory contents rather than to the general organization of memory.

In a related study, Beaty and Silvia (2012) examined the temporal sequence of divergent-thinking responses across time, providing a direct test of whether associative processes contribute to creative output. This *serial-order effect*—the tendency for the creative quality of ideas to increase over time—reflects a principle of the associative theory; that is, the creative thought process takes time, so that increasingly novel associations can be established. The serial-order effect has been replicated across many studies (Milgram & Rabkin, 1980; Wallach & Kogan, 1965; Ward, 1969). Beaty and Silvia (2012), however, found that fluid intelligence (Gf) moderated this temporal pattern: As Gf increased, the serial-order effect diminished. Time was thus unnecessary for more-intelligent participants to come up with creative ideas. Beaty and Silvia (2012) suggested that this effect was driven by executive control mechanisms, such as the ability to inhibit the salient but unoriginal ideas that typically come to mind at the beginning of a divergent-thinking task (Gilhooly et al., 2007).

The controlled-attention theory of creativity

A more recent theory of creative cognition is the *controlled-attention theory*. According to this framework, creative thought is a top-down process that taps individual differences in the ability to control attention and cognition. Several recent studies have examined a range of controlled processes in creativity, such as fluid intelligence (Gf; Beaty & Silvia, 2012, 2013; Benedek, Franz, Heene, & Neubauer, 2012; Jauk, Benedek, & Neubauer, 2014; Silvia & Beaty, 2012) and working memory capacity (De Dreu, Nijstad, Bass, Wolsink, & Roskes, 2012; Lee & Therriault, 2013; Süß, Oberauer, Wittmann, Wilhelm, & Schulze, 2002). This emerging literature suggests that controlled processes provide goal-directed, top-down oversight during creative idea production.

Individual differences in creative cognition are often assessed with divergent-thinking tasks (Kaufman et al., 2008). The classic divergent-thinking task is the alternate-uses test, which involves generating alternate uses for a common object (e.g., a brick). The most salient associations to the object—the least novel ideas—often come to mind first (e.g., "build a brick house"), thus disrupting the search process (Gilhooly et al., 2007). Controlled attention is therefore required to inhibit these sources of interference and to shift the search process to more productive semantic categories. Indeed, Nusbaum and Silvia (2011) found that executive switching—the ability to shift between semantic categories—mediated the effect of Gf on divergent thinking. This suggests that Gf may facilitate creative thought by exerting cognitive control. Because Gf is strongly associated with working memory and controlled attention (Engle, Tuholski, Laughlin, & Conway, 1999), Beaty and Silvia (2012) proposed that inhibitory processes help to suppress the earliest and most unoriginal responses during divergent thinking.

Broad retrieval ability (Gr; Carroll, 1993) has also been shown to support creative thought. Gr is most often assessed with verbal fluency tasks (e.g., letter fluency), which require participants to retrieve as many exemplars from a category as possible (e.g., listing words that start with the letter *M*). Such tasks have long been used as benchmark assessments of executive functioning in neuropsychological research (Henry, Crawford, & Phillips, 2004; Troyer, Moscovitch, Winocur, Alexander, & Stuss, 1998). Verbal fluency is thought to require controlled attention because it involves the generation and maintenance of retrieval cues (Unsworth, 2009) and online monitoring of intrusions and repetitions during memory retrieval (Conway & Engle, 1994; Unsworth & Engle, 2007).

Several recent studies have demonstrated a key role of Gr in creative idea generation (Beaty & Silvia, 2013; Benedek, Könen, & Neubauer, 2012; Gilhooly et al., 2007; Silvia, Beaty, & Nusbaum, 2013). For example, Silvia et al. (2013) administered a battery of verbal fluency tasks, representing a spectrum of Gr subfacets (Carroll, 1993), and assessed divergent thinking. Structural equation models showed large effects of the different Gr subfacets on divergent thinking. Importantly, the subfacets that placed the greatest demands on retrieval showed the largest effects on divergent thinking (e.g., word fluency—listing words that do not contain the letters *E* or *R*), thus pointing to a role of controlled attention. In a related study, Benedek, Könen, and Neubauer (2012) found that performance on several verbal fluency tasks explained over half of the variance in divergent-thinking ability. Taken together, the ability to strategically search memory, through the generation and maintenance of retrieval cues, appears to play a central role in creative idea production.

The present research

A growing body of evidence supports the controlled-attention theory of creativity—the notion that creative thought is strategic and controlled (Beaty & Silvia, 2012, 2013; Benedek et al., 2014; Benedek, Bergner, Könen, Fink, & Neubauer, 2011; Benedek, Könen, & Neubauer, 2012; Chein & Weisberg, 2014; De Dreu et al., 2012; Jauk et al., 2014; Lee & Therriault, 2013; Nusbaum & Silvia, 2011; Nusbaum, Silvia, & Beaty, 2014; Silvia & Beaty, 2012; Süß et al., 2002). A separate literature also provides support for the associative theory—the notion that creative thought is unconscious and associative (Baird et al., 2012; Bowden et al., 2005; Dijksterhuis & Meurs, 2006; Kounios et al., 2006; Mednick, 1962; Sio & Ormerod, 2009; Zhong, Dijksterhuis, & Galinsky, 2008). This raises the question of whether creative thought relies on associative processes, executive processes, or both. In the present research, we sought to address this question by exploring the extents to which associative and executive abilities contribute to creative cognition.

To assess associative ability, we used latent semantic analysis (LSA; Landauer, Foltz, & Laham, 1998). LSA quantifies the semantic similarity between words in a given semantic space by determining the probability of a given word occurring in a specific context (e.g., a paragraph of text). The LSA software compares inputted terms with a large corpus of text and assigns a coefficient representing semantic similarity. A similar approach has recently used LSA to assess creative cognition (Green, Fugelsang, & Dunbar, 2006; Green, Fugelsang, Kraemer, & Dunbar, 2008; Prabhakaran, Green, & Gray, 2013). For example, Prabhakaran et al. administered a variation of the verb generation task (Petersen, Fox, Posner, Mintun, & Raichle, 1989) that required participants to quickly produce verbs in response to a series of nouns. In a cued condition, participants were cued to respond with a verb that related to a noun creatively; in an uncued condition, they simply responded with a typical verb. The responses were then submitted to LSA, and a measure of semantic distance was computed (i.e., the inverse of semantic similarity). In contrast to the uncued condition, the cued condition was related to a wide range of behavioral measures, such as fluid intelligence, divergent thinking, and creative achievement.

Here, we employed LSA to explore individual differences in associative abilities. Using the "one-to-one" comparison function (see http://lsa.colorado.edu), we calculated semantic distance values of responses generated during verbal fluency tasks. Participants completed two associational fluency tasks (e.g., listing synonyms for the word *hot*), and their responses were compared for semantic similarity to the target word (*hot*) ; we then derived a value of semantic distance by computing the inverse of the semantic similarity coefficients (Prabhakaran et al., 2013). This provided an assessment of associative ability—an individual difference reflecting variation in the organization of concepts in memory. Large semantic distance values, then, represented a loosely structured knowledge base, similar to the notion of flat associative hierarchies (Mednick, 1962).

We used this measure of associative ability, along with several measures of cognitive ability, to determine the extents to which associative and executive processes contribute to the creative quality of divergent-thinking responses. If both associative and executive processes are important to creative cognition, we would expect to see simultaneous effects of both semantic distance and cognitive control variables on divergent thinking. On the other hand, if creative cognition relies mostly on executive processes, we would expect cognitive ability to predict divergent thinking, with no significant contribution of associative ability. But if creativity is largely an associative process, we would expect associative ability to emerge as the only significant predictor of creative thought.

Study 1

In our first study, we explored the extent to which semantic distance predicts the quantity and quality of divergent-thinking responses. Participants completed two measures of associational fluency (Carroll, 1993), and their responses were submitted to a latent semantic analysis. We also assessed the contributions of broad retrieval ability (Gr) and crystallized intelligence (Gc) to determine their relative contributions to divergent thinking, beyond semantic distance. Because Gr (a measure of executive ability) and Gc (a measure of general knowledge) had predicted creativity in previous studies (e.g., Beaty & Silvia, 2013; Silvia et al., 2013), we expected these variables to show notable effects on divergent thinking in the present study.

Method

Participants

The data presented here were reanalyzed from a recently published study on verbal fluency and creativity (see Silvia et al., 2013). The sample was 147 undergraduate students from the University of North Carolina at Greensboro (UNCG; 120 women, 27 men: mean age = 19.68, *SD* = 4.67). The self-reported ethnicities of the sample were 22.4 % African American, 8.2 % Asian, 65.3 % European American, 4.8 % Hispanic, and 10 % Native American (more than one option could be selected). Students received credit toward a research option in a psychology course for their participation.

Procedure

The study was completed in groups of one to eight. Students were given consent forms and briefed on the purpose of the study. Upon providing informed consent, students completed a series of creativity and intelligence tasks. All measures were administered on desktop computers using MediaLab v2010 software.

Divergent thinking To assess creative cognition, we administered two divergent-thinking tasks: alternate uses for a box and a rope. Divergent-thinking tasks are probably the most widely used tasks for measuring individual differences in creative thought (Kaufman et al., 2008). The large literature on divergent thinking provides extensive evidence for the validity of these tasks. For example, divergent-thinking performance correlates with self-reported creative achievement in cross-sectional studies (e.g., Jauk et al., 2014), predicts expert ratings of creative performance (e.g., Beaty et al., 2013), and prospectively predicts creative accomplishments across several decades in longitudinal research (e.g., Plucker, 1999). The instructions encouraged participants to "be creative" and "to come up with something clever, humorous, original, compelling, or interesting." Tasks were timed for 3 min each, and participants typed their ideas into response boxes using the MediaLab software. Responses were subsequently scored by two trained raters using the snapshot scoring method (Silvia, Martin, & Nusbaum, 2009). In this form of subjective scoring, each participant receives a single score that represents the creative quality of the entire set of responses. Raters coded the response sets independently, using a scale from 1 (*not at all creative*) to 5 (*very creative*). Responses were judged based on the criteria of remoteness, novelty, and cleverness (Benedek, Mühlmann, Jauk, & Neubauer, 2013; Christensen et al., 1957; Silvia et al., 2008). A measure of fluency was also derived by summing the total number of responses.

Gr We administered two verbal fluency tasks that capture associative flexibility (Carroll, 1993). In the associative flexibility tasks, a prompt word was presented, and participants were asked to generate a list of linked words in which each word was related to the prior word (Benedek, Könen, & Neubauer, 2012). For the prompt *music*, for example, participants might have a list like *music*, *artist*, *exhibition*, and *picture*. We used *music* and *cold* as prompt words. Participants had 1 min to work on each task. The tasks were scored conventionally by summing the total number of distinct responses for each task.

Semantic distance We administered two associational fluency tasks to assess semantic distance. These associational fluency tasks required participants to list synonyms for the words *good* and *hot*, and the responses were then analyzed using latent semantic analysis (LSA). Two separate analyses were conducted, one for each task. For both analyses, we used the *one-to-one* comparison and a topic space of "general reading up to first year college (300 factors)." Each person's response set was entered into the LSA software and compared to the cue word (e.g., *good*). The software assigned a coefficient to each response on the basis of its semantic similarity to the cue (e.g., *good–best* = .63). We then computed an average semantic similarity score for each participant. Finally, we computed the inverse of the average to derive a metric of semantic distance (where 1 = *average similarity*; Prabhakaran et al., 2013).

Crystallized intelligence (Gc) To assess general knowledge, we administered two vocabulary tests from the ETS Kit of Factor-Referenced Cognitive Tasks: the Advanced Vocabulary Test II (18 items, 4 min) and the Extended Range Vocabulary Test (24 items, 4 min; Ekstrom, French, Harman, & Dermen, 1976). The tasks were presented in multiple-choice formats, with a target word and a series of four to five answer choices. Participants were instructed to select the word that best described the target word.

Results

Data screening and model specification

Correlations and descriptive statistics for the unstandardized variables are presented in Table 1. The data were analyzed with multivariate structural equation models in Mplus 7, using maximum likelihood estimation with robust standard errors. All variables were standardized by *z* transformation prior to analysis. Fluency was also modeled as a latent variable, indicated by the total number of responses on the box and rope tasks. Likewise, Gr and Gc were modeled as latent variables, indicated by performance on their respective tasks.

Creativity was modeled as a higher-order latent variable, indicated by two lower-order latent variables (see Fig. 1); these lower-order variables—box and rope—were in turn indicated by the scores of the two raters.

To estimate interrater reliability, we used the maximal reliability *H* statistic (Drewes, 2000; Hancock & Mueller, 2001; Silvia, 2011). *H* represents the proportion of variance explained by the indicators of a latent variable (Hancock & Mueller, 2001). Unlike conventional reliability metrics (e.g., Cronbach's alpha), *H* does not assume tau equivalence (i.e., equal factor loadings for each indicator); instead, it allows the factor loadings to vary, thus recognizing that some items contribute more to construct reliability. But, similar to Cronbach's alpha, *H* is influenced by the number and magnitude of the indicators. Reliability estimates for the two tasks were good (box H = .73, rope H = .61), suggesting adequate interrater reliability. *H* for the higher-order creativity variable was .81.

The verbal fluency responses were first screened for repetitions and spelling errors. Repetitions were not included in the final score; spelling errors were corrected and maintained for analysis, but only if the error was obvious. We then computed semantic distance values for each of the two tasks (i.e., 1 = *average semantic similarity*); these observed scores were then modeled as indicators of a latent semantic distance variable. For model identification, the paths of the latent variables were constrained to be equal, and the variances of the latent variables were fixed to 1 (Kline, 2011).

Structural equation models

Our first model assessed the role of semantic distance in divergent-thinking creativity and fluency. A model with the latent semantic distance variable predicting the latent creativity and fluency variables showed good fit: $\chi^2(18) = 32.09$, $p = .02$, CFI = .947, SRMR = .043, RMSEA = .073 (90 % confidence interval [CI] = .02, .11). Latent semantic distance strongly predicted creativity (β = .47) and showed a moderate effect on fluency ($\beta = .33$; see Table 2): As average semantic distance increased, the quality and quantity of creative ideas increased. This model explained 22 % of the variance in creativity and 11 % of the variance in fluency, providing initial support for the notion that individual differences in associative abilities contribute to creative cognition.

We then examined the effects of Gr and Gc to determine their relative influences beyond semantic distance. First, we modeled creativity and fluency as multivariate outcomes predicted by Gr and Gc; this model showed good fit: $\chi^2(31)$ = 48.86, p = .02, CFI = .952, SRMR = .043, RMSEA = .063 (90 % CI = .02, .09). The model showed a significant effect of Gr (β = .38) and a marginal effect of Gc (β = .27) on divergent-thinking creativity. Regarding divergent-thinking fluency, Gr (β = .35) showed a moderate effect, and Gc

Table 1 Correlations and descriptive statistics: Study 1

	M	*SD*	Min, Max	1	2	3	4	5	6	7	8	9	10	11	12
1. DT Rope: Rater 1	1.74	0.86	1.00, 5.00	1											
2. DT Rope: Rater 2	2.20	0.74	1.00, 4.00	.44	1										
3. DT Box: Rater 1	1.92	0.89	1.00, 5.00	.35	.38	1									
4.DT Box: Rater 2	2.05	0.73	1.00, 5.00	.33	.30	.57	1								
5. DT Rope: Fluency	7.52	4.07	1.00, 22.00	.12	.23	.11	.17	1							
6. DT Box: Fluency	7.91	4.09	1.00, 22.00	.06	.08	.25	.19	.72	1						
7. Sd Avg.: Hot	.70	.08	.48, .90	.16	.31	.12	.16	.20	.11	1					
8. Sd Avg.: Good	.66	.08	.41, .84	.10	.07	.10	.10	.15	.07	.23	1				
9. Gr: Music	12.41	4.66	1.00, 30.00	.15	.24	.17	.24	.15	.18	.13	.08	1			
10. Gr: Cold	11.97	4.37	3.00, 25.00	.13	.11	.28	.25	.25	.28	.08	.11	.64	1		
11. Gc: Advanced vocab	6.95	2.68	0.00, 14.00	.17	.06	.05	.17	.05	–.05	.04	.00	.17	.09	1	
12. Gc: Extended vocab	9.85	3.30	1.00, 18.00	.18	.22	.09	.19	–.01	–.07	.18	–.04	.13	.04	.46	1

n = 147. DT, divergent thinking; Sd Avg., semantic distance average; Gr, broad retrieval ability, Gc, crystallized intelligence

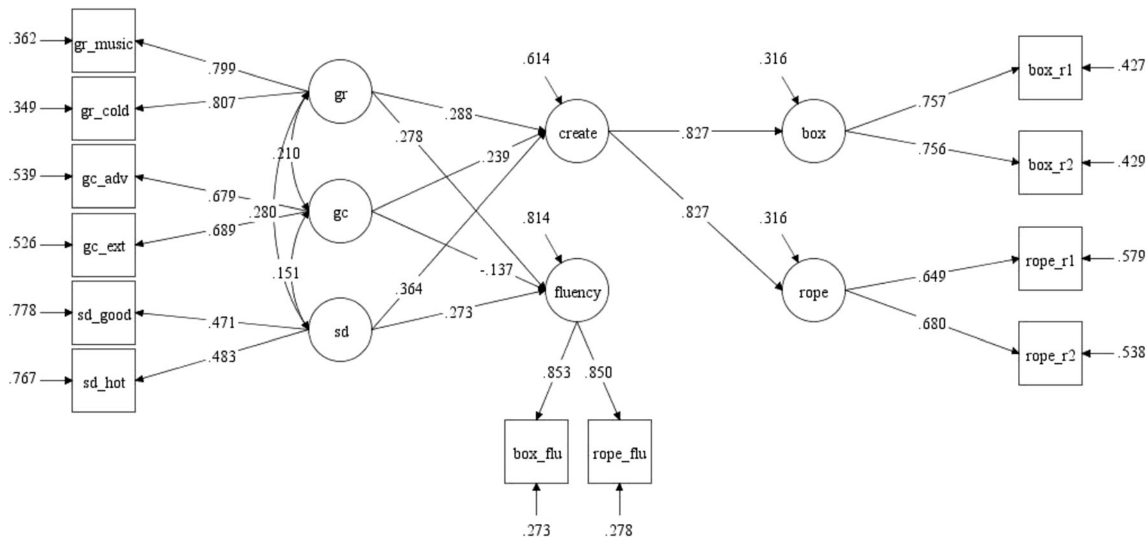

Fig. 1 Depiction of the structural equation model from Study 1

showed a small, nonsignificant effect (see Table 2). This model explained 26 % of the variance in creativity and 11 % of the variance in fluency. This suggests that individual differences in general knowledge, and in the ability to fluently recall such knowledge, are related to the quality and quantity of creative ideas.

Finally, we assessed the roles of semantic distance, Gr, and Gc in divergent thinking. A model with creativity and fluency predicted by semantic distance, Gr, and Gc showed good fit: $\chi^2(66) = 463.40$, $p = .00$, CFI = .953, SRMR = .047, RMSEA = .052 (90 % CI = .01, .08). Semantic distance ($\beta = .36$) and Gr ($\beta = .29$) both predicted the creative quality of divergent-thinking responses; Gc showed a medium but nonsignificant effect ($\beta = .24$; see Table 3). This model explained 39 % of the variance in creativity and 19 % of the variance in fluency. Notably, the model explained an additional 13 % of the variance in creativity, as compared to the model with only Gr and Gc, and an additional 8 % of the variance in fluency. Taken together, these results provide support for joint contributions of associative and executive abilities in creative cognition.

Table 2 Summary of latent regression effects: Study 1

	Creativity			Fluency		
Model	β	p	95 % CI	β	p	95 % CI
1. Sd						
Sd	.474	.010	.113, .835	.334	.008	.087, .580
2. Gr & Gc						
Gr	.382	.001	.134, .755	.350	.000	.157, .589
Gc	.271	.056	–.030, .662	–.114	.362	–.386, .143
3. Sd, Gr, & Gc						
Sd	.364	.039	.018, .710	.273	.057	–.008, .555
Gr	.288	.046	.006, .571	.278	.007	.077, .480
Gc	.239	.110	–.054, .531	–.137	.299	–.396, .122

n = 147. Sd, semantic distance average; Gr, broad retrieval ability; Gc, crystallized intelligence

Study 2

In Study 1, we found that associative abilities, assessed via semantic distance, strongly predicted the creative quality of divergent-thinking responses. We also found that executive abilities, assessed via Gr, predicted divergent thinking, controlling for semantic distance. In Study 2, we sought to replicate and extend these findings by exploring whether a second measure of executive ability—fluid intelligence (Gf)—predicts creativity when controlling for semantic distance. We also explored the role of personality, a well-established predictor of creativity (Feist, 1998; Silvia, Nusbaum, Berg, Martin, & O'Connor, 2009), to determine its relative influence beyond the effects of associative and executive processes. One notable limitation of Study 1 was the use of the same family of tasks (i.e., verbal fluency tasks) to derive measures of semantic distance and Gr. Study 2 overcame this limitation by using Gf tasks to assess executive processes. Although Gf and Gr both tap executive processes, Gf is more closely associated with working memory capacity and controlled attention (Unsworth, Redick, Lakey, & Young, 2010). Thus, in addition to a replication of Study 1, Study 2 provided a more robust assessment of executive abilities and a look at the role of personality in divergent thinking.

Method

Participants

A total of 185 undergraduate students from UNCG volunteered to participate and received credit toward a

Table 3 Correlations and descriptive statistics: Study 2

	M	*SD*	Min, Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. DT Box: Rater 1	1.54	0.43	1, 5	1													
2. DT Box: Rater 2	1.76	0.47	1, 4	.62	1												
3. DT Box: Rater 3	1.90	0.31	1, 3	.38	.33	1											
4. DT Box: Fluency	8.59	4.77	1, 27	–.30	–.16	–.15	1										
5. Sd Avg.: Happy	.67	.08	.46, .85	.18	.29	.01	.07	1									
6. Sd Avg.: Good	.66	.09	.31, .88	–.09	.08	.07	.10	.10	1								
7. Gf: Series completion	7.36	1.65	1, 11	.24	.12	.12	–.07	–.02	.04	1							
8. Gf: Paper folding	4.83	2.21	0, 9	.18	.18	.14	–.02	–.08	–.03	.40	1						
9. Gf: Letter sets	7.41	2.53	1, 13	.01	.09	.13	–.08	.00	–.03	.27	.36	1					
10. Neuroticism	3.14	0.60	1.33, 4.50	.05	.11	–.02	.12	–.06	.00	.03	.02	.06	1				
11. Extraversion	3.47	0.47	2.08, 4.58	.10	.00	.00	–.06	.00	.08	–.06	.00	–.01	–.32	1			
12. Openness	3.43	0.53	2.17, 5.00	.12	.19	.19	.00	.11	.03	.15	.07	.02	.09	.10	1		
13. Agreeableness	3.64	0.48	2.17, 4.83	–.02	–.12	–.03	–.09	–.02	–.14	.01	.00	.00	–.13	.14	.16	1	
14. Conscientiousness	3.58	0.54	2.08, 4.92	–.09	–.07	–.04	–.07	–.04	–.04	.03	–.13	.05	–.30	.04	.10	.15	1

n = 183. DT, divergent thinking; Sd Avg., semantic distance average; Gf, fluid intelligence

research participation option in a psychology course (42 men, 142 women, with one participant excluded [see the Results]; mean age = 18.51, *SD* = .99). The self-reported ethnicities were 38 % African American, 7.1 % Asian American, 50 % European American, 7.6 % Hispanic, and 2.2 % Native American (more than one option could be selected).

Procedure

The procedure was similar to that of Study 1. Students gave informed consent and worked in groups of one to eight on a series of computerized tasks and questionnaires.

Divergent thinking Participants had 3 min to generate alternate uses for a box. As in Study 1, they were instructed to "be creative" and "to come up with something clever, humorous, original, compelling, or interesting." We again used the subjective scoring method (Silvia et al., 2008) to code the creative quality of divergent-thinking responses. Three trained raters scored each response independently, using a 1 (*not at all creative*) to 5 (*very creative*) scale, on the basis of criteria of remoteness, novelty, and cleverness. Note that this scoring approach was different from that of Study 1, which had used the snapshot method to apply a single score to each set of responses. Here, three raters scored each divergent-thinking response individually. This allowed us to extend the results of Study 1 by using a second approach to creativity scoring. Finally, a measure of fluency was derived by summing the total number of responses.

Gf Participants completed three Gf tasks. In a paper-folding task (Ekstrom et al., 1976), they were presented images of pieces of paper being folded and punched with a hole; they had to determine the final state of the paper when it is completely unfolded (ten items, 3 min). In a series completion task (Cattell & Cattell, 1961/2008), participants were presented a series of images drawn within small boxes that changed in succession; they had to discover the rule guiding the changing images and determine the next item in the series (13 items, 3 min). Finally, in a letter set task (Ekstrom et al., 1976), participants were presented four sets of four letters of the alphabet; they had to determine which set violated a rule that governed the other three sets (16 items, 4 min).

Personality Participants completed the NEO Five Factor Inventory (NEO-FFI-3; McCrae & Costa, 2007) to assess the five major factors of personality: neuroticism, extraversion, openness to experience, agreeableness, and conscientiousness (60 items). Each factor was measured with 12 items, and participants responded to each item using a 5-point scale (1 = *strongly disagree*, 5 = *strongly agree*).

Results

Data reduction and model specification

Correlations and descriptive statistics for the unstandardized variables are presented in Table 3. One participant was excluded on the basis of multivariate outlier statistics (i.e., Cooks distance > 1). As in Study 1, the verbal fluency data were used to compute semantic distance values, and we screened repeated responses. We then proceeded to analyze these data using structural equation modeling. Creativity was modeled as a latent variable indicated by the three raters' scores on the box task; fluency was modeled as an observed variable (see Fig. 2). We again computed the *H* statistic to assess the

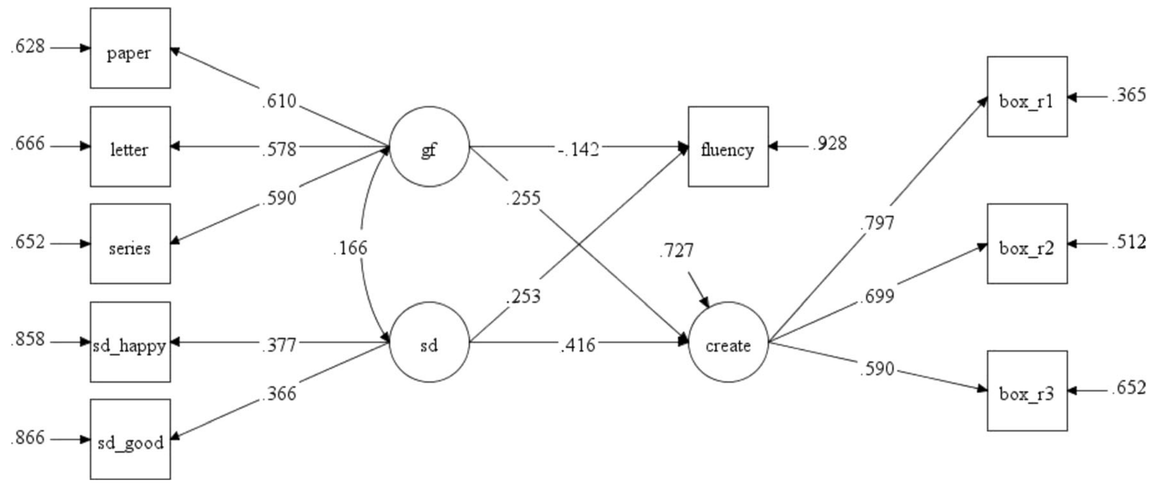

Fig. 2 Depiction of the structural equation model from Study 2

reliability of the creativity variable, which was good (H = .76). Similarly, Gf was modeled as a latent variable indicated by performance on the three inductive reasoning tasks. The indicators of each latent variable were constrained to be equal, and the latent variable variances were fixed to 1 (Kline, 2011). All variables were standardized by z-transforming the raw scores.

Structural equation models

We began by attempting to replicate the results of Study 1. A model with semantic distance predicting divergent-thinking creativity and fluency was specified. The model fit was adequate: $\chi^2(10) = 34.649$, $p = .00$, CFI = .825, SRMR = .077, RMSEA = .117 (90 % CI = .076, .161). As in Study 1, semantic distance strongly predicted divergent-thinking creativity (β = .46, R^2 = .21; see Table 4). Interestingly, the magnitude of this effect was nearly identical to that from our first study (β = .47). The similarity of these effects is especially notable, in light of the different tasks used to assess semantic distance, the use of a single divergent-thinking task, and the different methods used to score divergent thinking. The effect of semantic distance on divergent-thinking fluency was modest and not significant (β = .23); this effect was smaller than in Study 1 (β = .33), possibly due to the use of a single observed task.

With our next model, we assessed the role of Gf. Before testing the full model, with semantic distance, Gf, and personality, we first attempted to establish the unique effect of Gf. A model with Gf predicting divergent-thinking creativity and fluency showed adequate fit: $\chi^2(16) = 31.524$, $p = .01$, CFI = .912, SRMR = .061, RMSEA = .073 (90 % CI = .03, .11). Gf showed a moderate effect on creativity (β = .32) and a small, negative effect on fluency (β = –.10). This model explained 11 % of the variance in creativity and only 1 % of the variance in fluency. Thus, as intelligence increased, the quality, but not the quantity, of divergent-thinking responses increased. This analysis replicated past research on intelligence and divergent thinking (e.g., Beaty & Silvia, 2012; Benedek, Franz, et al., 2012; Jauk, Benedek, Dunst, & Neubauer, 2013).

Next, we added semantic distance to a model with Gf predicting divergent-thinking creativity and fluency. This permitted a test of whether associative and executive abilities are both important to creative thought. The specified model showed adequate fit: $\chi^2(27) = 52.536$, $p = .00$, CFI = .876, SRMR = .063, RMSEA = .072 (90 % CI = .04, .10). Semantic distance (β = .42) and Gf (β = .26) both significantly predicted divergent-thinking creativity; neither variable predicted fluency (see Fig. 2 and Table 4). This model explained 27 % of the variance in creativity—an additional 6 % of variance from a model with only the semantic distance variable. Notably, the correlation between Sd and Gf was small and nonsignificant (r = .16, p = .41), suggesting minimal overlap between the two constructs.

Our final model included semantic distance, Gf, and personality. We were particularly interested in the personality factor Openness to Experience, the most consistent predictor of creativity (Silvia, Nusbaum, et al., 2009), and the extents to which semantic distance and Gf would predict divergent thinking, controlling for personality. A model with semantic distance, Gf, and five factors of personality predicting creativity and fluency showed good fit: $\chi^2(62) = 96.904$, $p = .00$, CFI = .850, SRMR = .055, RMSEA = .055 (90 % CI = .03, .07). Of the five factors, only openness significantly predicted creativity (β = .22). Openness, however, did not reduce the effects of the cognitive variables: Sd (β = .35) and Gf (β = .23) remained robust predictors of creativity (see Table 4). Interestingly, this model also explained the same proportion of variance in creativity as did the model with Gf and semantic distance (R^2 = .27). Taken together, these results suggest that both associative and executive abilities are important to the creative thought process.

Table 4 Summary of latent regression effects: Study 2

Model	DT Creativity			DT Fluency		
	β	*p*	95 % CI	*β*	*p*	95 % CI
1. Sd						
Sd	.460	.012	.100, .820	.229	.165	–.094, .553
2. Sd and Gf						
Sd	.416	.027	.047, .784	.253	.154	–.095, .600
Gf	.255	.026	.030, .480	–.142	.225	–.371, .087
3. Sd, Gf, and Personality						
Sd	.352	.050	.000, .704	.241	.175	–.112, .591
Gf	.233	.035	.016, .450	–.149	.184	–.371, .075
Neuroticism	.055	.541	–.122, .233	.104	.158	–.041, .249
Extraversion	.066	.446	–.105, .238	–.025	.756	–.181, .131
Openness to experience	.216	.013	.046, .387	.007	.917	–.135, .150
Agreeableness	–.117	.152	–.278, .043	–.053	.491	–.205, .098
Conscientiousness	–.083	.324	–.248, .082	–.026	.736	–.178, .126

n = 183. DT, divergent thinking; Sd, semantic distance average; Gf, fluid intelligence

Discussion

In two studies, we examined the contributions of associative and executive abilities in creative cognition. Using a novel approach to assess associative abilities (i.e., LSA) and a battery of assessments of cognitive abilities, the present research suggests that both executive and associative processes support divergent-thinking ability. Across both studies, the average semantic distance of responses generated during verbal fluency tasks strongly predicted the creative quality of responses. Furthermore, individual differences in executive abilities, assessed via Gr (Study 1) and Gf (Study 2), also predicted creativity, controlling for associative ability. Taken together, the present work supports the predictions of two theories of creativity—the associative and controlled-attention theories—by demonstrating the importance of both associative and executive processes in divergent thinking.

Our first study established the effect of semantic distance on divergent thinking. This approach extends recent research that has used LSA to assess creativity (Green et al., 2006; Green et al., 2008; Prabhakaran et al., 2013). Of note, however, was the predictive power of semantic distance values computed from a task unrelated to creative cognition. Prabhakaran et al. found an effect of semantic distance on creativity only when participants were cued to generate a creative verb. For our study, we simply asked participants to generate synonyms, and the average semantic distance between their responses and the cues strongly predicted divergent thinking. This measure of semantic distance provided a measure of associative ability similar to the notion of associative hierarchies (Mednick, 1962).

The effect of semantic distance on creativity remained substantial when Gr was included in a latent-variable model predicting divergent thinking. This provides support for roles of both associative and executive abilities in creativity. Although semantic distance was correlated with Gr (r = .28) and Gc (r = .15), the magnitude of these latent correlations was not large enough to suggest substantial overlap between the constructs. This was particularly notable in light of the fact that semantic distance and Gr were calculated using the same types of tasks (i.e., verbal fluency tasks), and the fact that all three variables tap aspects of semantic memory retrieval.

Our second study replicated the effect of semantic distance on divergent thinking. Interestingly, the magnitudes of the effect were virtually the same in Study 1 and Study 2 (i.e., β = .47 and .46, respectively), despite different verbal fluency tasks being used for LSA and a different creativity scoring method being applied to a single task. As in Study 1, in Study 2 we found joint contributions of associative and executive abilities in divergent thinking. These effects were robust to the addition of personality factors to a model predicting creativity. Although openness was modestly correlated with semantic distance and Gf, this did not appreciably diminish the effect of either variable. Taken together, the results of these two studies help to reconcile the associative and executive theories of creativity.

Integrating associative and controlled attention theories

How might the associative and controlled-attention theories be rectified? On the one hand, our results suggest that bottom-up, associative processes may influence creative thought, which may be related to differences in the structure of semantic memory. On the other hand, several top-down processes appear to provide executive control during divergent thinking. Fluent retrieval from semantic memory, for example, involves the generation and maintenance of cues during memory search (Conway & Engle, 1994; Unsworth, 2009; Unsworth & Engle, 2007). The joint effects of semantic distance and retrieval ability (i.e., verbal fluency) in Study 1 thus suggest that the structure of knowledge and the ability to fluently extract knowledge are important to the creative thought process. In Study 2, the effect of Gf points to a role of inhibitory control and executive switching during idea generation, such as inhibiting salient and highly related conceptual information (Beaty & Silvia, 2012) and shifting the search process between several different semantic categories (Nusbaum & Silvia, 2011). Taken together, a loosely structured knowledge base may support creative thought, as was evidenced by the large univariate effects of semantic distance in both studies. But top-down control over such knowledge also appears to be important, as evidenced by the contributions of Gf and Gr, controlling for semantic distance.

Clearly, future research will be needed before further conclusions can be made. We see the present studies as a first step in reconciling two theories of creative cognition. The associative theory has been the prevailing view of creative thought since creativity was first brought under empirical scrutiny (Mednick, 1962; Runco, 2007; Wallach & Kogan, 1965). But the growing body of literature pointing to a role of controlled cognitive processes raises the question of whether creativity is solely a passive process.

To further reconcile the associative and executive theories, a dual-process model may be the best approach (cf. Barr, Pennycook, Stolz, & Fugelsang, 2014). Such models can accommodate both automatic and controlled cognitive processes (Evans, 2003; Kahneman, 2003). Like many basic cognitive functions (e.g., episodic memory retrieval), automatic and controlled processes appear to be intimately involved, and the present work suggests that creative thought is another case in point. A key challenge for future research will be to understand how associative and executive processes interact to yield creative output. Recently, Barr and colleagues found that people's willingness and ability to override automatic response tendencies and to engage controlled processes predicted individual differences in divergent-thinking performance (Barr et al., 2014). Such work provides a promising approach to understanding the relative contributions of automatic and controlled processes in creative thought.

Limitations and future directions

In two studies, we demonstrated roles of both associative and executive processes in creative cognition. We used LSA to assess associative abilities, a novel approach that further validates the use of LSA in creativity research (Green et al., 2006; Green et al., 2008; Prabhakaran et al., 2013). Using structural equation models, we found that our measure of semantic distance formed a reliable latent variable across two studies. The analyses would have further benefited from using more than two fluency tasks to form a latent semantic distance variable. Future research should use a range of tasks when modeling semantic distance and continue to use LSA as a means to objectively score associative processes in creativity. Our conclusions are also limited by the scope of the creativity assessment included in both studies (i.e., divergent thinking). Although divergent-thinking tests appear to be reliable and valid measures of domain-general creative cognition, the extent to which they capture other facets of creativity remains unclear. We therefore encourage researchers to explore whether semantic distance predicts other facets of creativity, such as creative achievement.

Finally, the extent to which our measure of semantic distance was a pure measure of associative ability remains unclear. Because the measure was derived from verbal fluency tasks—that is, assessments of executive function—the average distance between associates to a given prompt may also have benefited from executive processes. Nevertheless, the correlations of semantic distance with Gf and Gr were relatively low (r = .17 and .28, respectively). The latter finding is particularly notable in light of the fact that both measures were derived from the same family of tasks. In summary, the present research offers the first evidence for joint contributions of associative and executive processes in divergent thinking, and paves the way for future research to further uncover the underlying mechanisms involved in creative cognition.

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