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The cognitive underpinnings of creative thought: A latent variable analysis exploring the roles of intelligence and working memory in three creative thinking processes

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ABSTRACT

The field of creativity has largely focused on individual differences in divergent thinking abilities. Recently, contemporary creativity researchers have shown that intelligence and executive functions play an important role in divergent thought, opening new lines of research to examine how higher-order cognitive mechanisms may uniquely contribute to creative thinking. The present study extends previous research on the intelligence and divergent thinking link by systematically examining the relationships among intelligence, working memory, and three fundamental creative processes: associative fluency, divergent thinking, and convergent thinking. Two hundred and sixty five participants were recruited to complete a battery of tasks that assessed a range of elementary to higher-order cognitive processes related to intelligence and creativity. Results provide evidence for an associative basis in two distinct creative processes: divergent thinking and convergent thinking. Findings also supported recent work suggesting that intelligence significantly influences creative thinking. Finally, working memory played a significant role in creative thinking processes. Recasting creativity as a construct consisting of distinct higher-order cognitive processes has important implications for future approaches to studying creativity within an individual differences framework.

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1. Introduction

Creative problem solving involves the generation of novel approaches to complex problems to develop innovative ideas and solutions (Batey & Furnham, 2006; Runco, 2007). Although the importance of creative thinking is acknowledged in educational and professional contexts, creativity remains a construct that is actively debated in the psychological literature (Dietrich & Kanso, 2010; Plucker, Beghetto, & Dow, 2004). Researchers studying the cognitive underpinnings of creativity are examining specific associative (e.g., Benedek, Konen, & Neubauer, 2012), divergent (e.g., Cho, Nijenhuis, Vianen, Kim, & Lee, 2010; Nusbaum & Silvia, 2011), and convergent (e.g., Brophy, 2000; Finke, Ward, & Smith, 1992; Ward, Smith, & Vaid, 1997) thinking processes in creativity. In addition, contemporary creativity research shows that fluid intelligence (e.g., Silvia, 2008b; Sub, Oberauer, Wittmann, Wilhelm, & Schulze, 2002), crystallized intelligence (e.g., Cho et al., 2010; Sligh, Conners, & Roskos-Ewoldsen, 2005), and executive functions (e.g., Gilhooly, Fioratou, Anthony, & Wynn, 2007; Nusbaum & Silvia, 2011) also play central roles in creative thinking. Taken together, modern creativity research is delineating specific creative processes and re-examining the relationship between these processes and higher-order cognition.

The aim of this study was to contribute to the emerging field of creative cognition by exploring the role of various cognitive

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abilities and processes involved in creativity. Drawing from recent research that underscores the importance of intelligence in creative thinking, structural equation modeling was used to explore the roles of intelligence and working memory in three specific creative–cognitive processes: associative fluency, divergent thinking, and convergent thinking.

2. Cognitive processes involved in creativity

To better understand the underlying cognitive mechanisms of creative production, it is important to appreciate the diverse mental processes that make up creative thinking. Many researchers have proposed that creativity involves both deliberate and spontaneous, or explicit and implicit, thinking processes (e.g., Arden, Chavez, Grazioplene, & Jung, 2010; Csikszentmihalyi, 1999; Eysenck, 1995; Finke, 1996; Kaufman, DeYoung, Gray, Brown, & Mackintosh, 2009; Martindale, 1995). Similarly, creativity researchers also argue that seemingly contradictory processes such as divergent thinking and convergent thinking serve complementary functions in the creative process (e.g., Brophy, 2000; Dietrich, 2004; Runco, 2007). Below, we review three specific cognitive processes that have garnered significant attention in creativity research.

2.1. Divergent thinking

Guilford (1967) distinguished between divergent thinking and convergent thinking in his structure of intellect (SI) model, emphasizing divergent thinking as a critical creative process. Divergent thinking is an inductive, ideational process that involves generating a broad range of solutions or ideas to a given stimulus (Guilford, 1967; Runco, 2007). It is often contrasted with convergent thinking, a deductive process that involves systematically applying rules to arrive at a single, correct solution (Brophy, 1998; Guilford, 1967). Divergent thinking is prominently assessed by pencil-and-paper tests that present open-ended prompts (e.g., "Think of as many unusual uses as possible for a wooden pencil", Guilford, 1967; Guilford, Merrifield, & Wilson, 1958). A participant's goal in these tests is to generate as many responses as possible. Responses are typically scored according to a standardized procedure; assessing creativity indicators, such as fluency, originality, and flexibility (Batey & Furnham, 2006; Goff & Torrance, 2002; Plucker & Renzulli, 1999). This psychometric approach to studying creativity provides an objective procedure to administer and score creativity, contributing to their appeal when conducting experimental studies (Sternberg & Lubart, 1996).

Although divergent thinking tests were originally developed to measure individual differences in ideation, these tests have become the primary method of studying creativity; many current approaches to assessing creative thinking employ the same materials and methods proposed over fifty years ago (Plucker & Renzulli, 1999; Simonton, 2000). This may be surprising given that evidence for the validity of divergent thinking tests is mixed. It has been pointed out that divergent thinking tests reduce the study of creativity to statistically rare responses specific to a given sample, leading to psychometric issues with larger samples when using traditional scoring procedures (Nusbaum & Silvia, 2011) and oversimplifying the criteria for creativity to merely generating a large amount of different ideas to unrealistic situations (Barron & Harrington, 1981; Cattell, 1971; Kim, 2005, 2006; Simonton, 2000; Sternberg & Lubart, 1996).

In other studies, performance on divergent thinking tests has been linked to real-life creative behaviors. In a review of creativity research, Barron and Harrington (1981) state that evidence for the validity of divergent thinking tests include positive and statistically significant relationships between divergent thinking test scores and various creativity indicators at the elementary, junior high school; undergraduate, and graduate levels. Early validation studies have shown that divergent thinking tests are highly correlated with measures of creativity in real life including: number of patents gained, producing plays and novels, and founding new businesses or professional organizations (Barron, 1963; Getzels & Jackson, 1962; Runco, 2004, Torrance, 1972; Wallas, 1926). More recent evidence for the predictive validity of divergent thinking tests has also been documented. For instance, a series of studies conducted by Hong and Milgram (1991), Hong, Milgram, and Gorsky (1995), Hong, Milgram, and Whiston (1993) provide evidence that performance on divergent thinking tests in early childhood and adolescence predicted real-life creative behaviors in domains including art, music, sport, drama, literature, and dance (Hong & Milgram, 1991; Hong et al., 1993, 1995). Finally, Plucker's (1999) re-analysis of Torrance's (1968, 1969) data from a longitudinal study of over 200 elementary students using structural equation modeling showed that divergent thinking strongly predicted creative achievements (e.g., inventions, awards, published articles) ($r = .60, p < .001$), explaining nearly half of the variance in adult creative achievement.

Divergent thinking tests continue to be the most widely used measure for assessing creativity (Batey & Furnham, 2006; Runco, 2010). Nevertheless, the sole use of these tests to assess and draw conclusions about an individual's overall creative potential is viewed as problematic, and there is insufficient evidence that creative cognition alone is psychometrically unitary (Arden et al., 2010). In this study, we treat divergent thinking as one of many cognitive processes in creative thinking, and explore the relationship of divergent thinking among other cognitive abilities and processes important for creativity, including convergent thinking and associative fluency.

2.2. Convergent thinking

Convergent thinking has been reported as both an antithesis (e.g., Guilford, 1967) as well as a complementary creativity process (e.g., Brophy, 2000). However, compared to divergent thinking, much less attention has been given to the role of convergent processes in creative thought. Convergent thinking tests measure cognitive processes that include discerning which ideas are most appropriate or of highest quality with the objective of arriving at a single, correct solution (Brophy, 2000; Guilford, 1967). Creativity tasks that engage convergent thinking processes include the Remote Associates Test (RAT, Mednick, 1962) as well as insight problems (e.g., Duncker's (1945) candle problem). The process of finding the solution to convergent thinking tests of creativity is often referred to as 'thinking outside of the box', as the problem-solver is required to break away from obvious responses and common mental sets in order to view the problem from an unusual perspective or novel search space where the solution resides (Wiley, 1998). For example, the RAT problems consist of a triad of cue words that are not directly related to each other, but rather, are related to a common associate fourth word, either through semantic association, synonymy, or formation of a compound word (e.g., bird, tie, pen → black; black bird, black tie, black pen). Often, the most common associates to each cue word (the words that first come to mind) are not related to the other cue words. Therefore, identifying the correct associate word requires the problem solver to suppress the strongest associates, and search for 'remote associates' of the three cue words (Mednick, 1962).

Arguably, the process of generating remote associates is also involved in divergent thinking, as greater performance on divergent thinking tests require the suppression of common responses in order to generate more novel and unusual responses (Gilhooly et al., 2007). Along the same line of thought, the RAT is likely to engage several cognitive processes that could be classified as associative (i.e., cueing an idea which cues another idea) or insight (e.g., Aha! experience). Support for these claims come from electroencephalography (EEG) studies showing that performance on the RAT is linked to alpha power changes in the right posterior regions of the brain, which reflect low cortisol activation, defocused attention, and unconscious processing (Jung-Beeman et al., 2004; Martindale & Hines, 1975; Razumnikova, 2007). However, what distinguishes convergent thinking tests from divergent thinking tests is that success on tests such as the RAT is determined by whether or not the problem solver has identified the single, correct solution—therefore, making the RAT and insight problems convergent in nature.

The unique contributions of divergent thinking and convergent thinking in creativity are important to address empirically, as the original design of commonly used divergent thinking and convergent thinking tests was based on distinct theoretical approaches. Broadly stated, the former was developed to assess ideation (Guilford, 1967) and the latter, to assess individual differences in making associations (Mednick, 1962). Yet in creativity literature, the distinction between divergent thinking tests and convergent creativity tests such as the RAT and insight problems has not been thoroughly acknowledged or empirically examined. For instance, interpretations of people's performance on the RAT and insight problems vary widely across studies; the RAT has been used to assess general creativity, creative problem solving, and even memory (e.g., Cushen & Wiley, 2012; Storm, Angello, & Bjork, 2011).

Early objections to interpreting the RAT scores as a measure of creativity have also been raised on both conceptual and empirical grounds. There is mixed evidence regarding whether differences in performance on the RAT actually relate to individual differences in associative abilities as originality proposed by Mednick (1962). Several studies showed that performance on the RAT was not related to the number of associations produced for a given stimuli (Yahav, 1965), weakly related to paired-associate learning ($r = .19$) (Greenberg, 1966), and unrelated to associative processes in a concept formation task (Jacobson, Elenewski, Lordahl, & Liroff, 1968). Furthermore, the convergent nature of the RAT items has been raised and it has been suggested that the RAT taps into executive functions more closely related to intelligence than associative processing (Greenberg, 1966; Jacobson et al., 1968; Laughlin, Doherty, & Dunn, 1968; Mendelsohn, 1976; Taft & Rossiter, 1966; Yahav, 1965). Taft and Rossiter (1966) showed that with few exceptions, tests convergent in nature, including school achievement, performance on verbal IQ, quantitative IQ, progressive matrices, speed and accuracy, and number series tasks, correlated considerably higher with the RAT (r ranging between .27 and .60) compared to the scores on tests of divergent thinking including ideational fluency, word fluency, and total fluency, flexibility, and originality scores on unusual and consequence tests (r ranging between .15 and .43). Similar studies have also shown moderately positive correlations between scores on the RAT test and conventional measures of intelligence ($r = .20$ to .50) (Laughlin et al., 1968). Finally, Mendelsohn (1976) showed evidence that even when controlling for verbal intelligence, performance on the RAT is related to individual differences in attentional processes, assessed by the employment of multiple category sets in solving anagrams. In other words, he proposed that the ability to find the single, correct mediating link (or remote associate) to solve the RAT problem was strongly dependent on higher-order attentional resources.

Despite the early controversies regarding the cognitive mechanisms and abilities assessed by the RAT, creativity researchers have by in large used and interpreted the RAT as a measure of general creative ability. Not until recently has the RAT been specified as a convergent thinking creativity task (e.g., Arden et al., 2010; Benedek et al., 2012; Kaufman, Kaufman, & Lichtenberger, 2011; Nielsen, Pickett, & Simonton, 2008). This trend towards determining operational creative processes is driven partly to the advances in neuroimaging techniques, for which psychometrically robust and consistent methods for assessing various cognitive processes in creativity is needed (Arden et al., 2010; Dietrich, 2004; Dietrich & Kanso, 2010). Increasingly, convergent thinking has been cited as an important process in creativity (e.g., effectively judging and adapting ideas generated in order to achieve a novel and appropriate solution), contrasting the early view that convergent processes are antithetical to creativity (Brophy, 1998, 2000). To assess the above claims, empirical research examining convergent and divergent thinking as separate creative processes is needed. As such, one of the major goals of the current study is to empirically explore the differences between performance on divergent thinking and convergent thinking tests.

2.3. Associative processing

In addition to exploring the differences between divergent thinking and convergent thinking, it may be fruitful to also examine their shared cognitive architecture. Drawing from the literature, a common cognitive process in divergent thinking and convergent thinking may be reliance upon some form of associative processing (Eysenck, 1995; Finke et al., 1992; Martindale, 1999; Wallas, 1926). To our knowledge, this proposition has not been directly tested. The study of associative processing in creativity emphasizes the recombination of existing elements into novel products that are available via spread of activation—the activation of mental networks made up of related (or associated) concepts and ideas. Mednick's (1962) theory of associative processes has been influential in studying associative abilities in creative thinking from an individual differences perspective. According to Mednick (1962), creative individuals have associative hierarchies (the gradient of associative response strength for available associations) that are flat allowing them to make many associations among remote ideas, form associative elements into novel combinations, and generate creative and useful solutions. Conversely, less creative individuals have steep associative hierarchies characterized by strong associative response strengths to common ideas, resulting in fewer and less novel associations (Mednick, 1962). In support of Mednick's theory, a study examining individual differences in associative processing showed that there was a negative and significant relationship between people's judgment of the associative distance between two stimuli words and their originality score on a series of creativity tests ($r = -.22, p < .05$) (Rossman & Fink, 2010). In other words, more creative individuals judged the associative distance between two unrelated words to be smaller than less creative individuals (Rossman & Fink, 2010). Research in the problem solving literature has also shown that people engage in a preliminary task analysis before engaging in the problem solving activity at hand, providing evidence that associative thinking (a memory search in which ideas are fluently retrieved) is a precursor to cognitive processes involved in developing and generating more complex and novel ideas (Ericsson & Simon, 1998; Gilhooly et al., 2007).

The role of associative processing in creativity has been well documented in the literature. In theory, associative processing is involved in both divergent thinking and convergent thinking. The activation and retrieval of remote associates are likely to support divergent processes where the goal is to generate many unusual solutions (e.g., "Think of as many uses for a brick as possible"). Similarly, the ability to initiate a wider associative spread to access remotely related concepts should also promote success on convergent creative thinking tests, where the goal is to identify a solution that is distally related from the original stimuli. It has been proposed that creative solutions are guided by implicit spreading activation (Bowers, Farvolden, & Mermigis, 1995), incremental steps in which the problem solver is building upon existing knowledge (Ward, 1994; Weisberg, 1995), unconscious activity that can be disrupted by simultaneously engaging in explicit tasks such as verbalization during the problem solving process (Dominowski, 1995), and associational and ideational fluency (Mendelsohn, 1976). However, only recently has the role of associative processes in creativity been directly explored.

Benedek et al. (2012) examined the role of associative processing, which was defined as the ability to fluently retrieve and combine remote associations, with respect to divergent thinking and intelligence. Four association tasks were developed to measured associative fluency (i.e., ability to make free-associations), associative flexibility (i.e., ability to create an association-chain in which the word generated is associated only to the word that precedes it), dissociative ability (i.e., ability to generate lists of unrelated words), and associative combination (i.e., ability to generate word that is associated with a pair of unrelated words). A latent variable analysis showed that dissociating and combining associations significantly predicted creativity ($\gamma = .28, p < .001, \gamma = .30, p < .05$, respectively), and associative flexibility predicted intelligence ($\gamma = .59$, $p < .05$). By exploring the unique contributions of distinct associative processes in both creativity and intelligence, findings from this study provide empirical evidence for the important role of associative thinking in both *g* and creative thinking.

Associative fluency tasks were originally developed to diagnose phonetic and semantic category-specific impairments due to neurological disorders such as aphasia (Benton, 1994). However these fluency tasks are believed to tap into people's ability to fluently retrieve and effectively organize verbal information. Fluency tasks have also been used in psychological studies to assess semantic memory (e.g., Collins & Loftus, 1975), fluid intelligence (e.g., Silvia 2008a, b) and associative processing (e.g., Benedek et al., 2012). In this study, the fluency tasks were used to assess associative fluency, operationalized as the ability to efficiently retrieve a broad range of associations.

Altogether, the review of the literature regarding cognitive mechanisms involved in divergent, convergent, and associative thinking support the hypothesized model in the present study. We propose that the process of fluently retrieving ideas from one's associative network (i.e., associative fluency) predicts both the ideational (i.e., divergent thinking) and analytic (i.e., convergent thinking) processes in creative thinking.

3. Intelligence and creative thinking

Many views on the relationship between creativity and intelligence exist. Early models of intellectual abilities generally placed creativity as a subset of intelligence (e.g., Cattell's model of fluid and crystallized intelligence, Cattell, 1971; Cattell-Horn-Carroll model, Carroll, 1993; Structure of Intellect Model, Guilford, 1967). Sternberg and Lubart's (1996) Investment Theory describes six components of creativity, specifying intelligence as one of the six subsets that make up creativity. Other empirical studies showed moderate relationships between creativity and intelligence measures, suggesting that intelligence and creativity are separate constructs with overlapping features (e.g., Cox, 1926; MacKinnon, 1965; Osborn, 1953; Spearman, 1904). Finally, some researchers proposed a nonlinear relationship between creativity and intelligence suggesting that intelligence (up to an IQ of 120) is a necessary, but not sufficient, condition for creative achievement (Barron, 1988; Barron & Harrington, 1981; MacKinnon, 1965). However, creativity researchers generally continue to view creativity and intelligence as unitary constructs that are modestly related at best (*r* ranging from approximately .17 to .39) (Batey & Furnham, 2006; Cho et al., 2010; Kaufman, 2009; Kim, 2008; Runco, 2007) and exactly how these two constructs are related remains an area of contentious debate.

A methodological limitation of the earlier studies of creativity and intelligence is that conclusions are almost entirely based on correlational analyses between various measures of intelligence and creativity. Recent studies using structural equation modeling to estimate intelligence and creativity as latent constructs indicate that these two constructs may be more strongly related than previously believed (e.g., Nusbaum & Silvia, 2011; Plucker, 1999; Silvia, 2008a,b; Vincent, Decker, & Mumford, 2002). For example, in a latent variable reanalysis of Wallach and Kogan's (1965) classic study, Silvia (2008a) found that creativity and intelligence were more highly related than reported in the original study. Compared to a correlation of $r = .09$ reported by Wallach and Kogan (1965), a latent creativity factor based on 10 different creativity scores was significantly related to a latent intelligence factor based on 10 intelligence and achievement scores ($\beta = .20$). Nusbaum and Silvia (2011) also showed that fluid intelligence predicted the ability to learn and apply a complex strategy in a divergent thinking test (Nusbaum & Silvia, 2011). In sum, recent research points to intelligence playing an important role in creative thought, specifically in divergent thinking. To date, a comprehensive examination of the role of intelligence in different creative processes, including associative, divergent, and convergent thinking has not been conducted. Therefore, a second aim of this study is to examine the role of intelligence in multiple creative processes.

4. Working memory and creative thinking

In light of studies that point to intelligence as a significant predictor of creative thinking, is it likely that executive processes related to intelligence also play a strong role in creative thought. In the psychological literature, executive functions have been somewhat of an umbrella term that refers to important higher order cognition including the monitoring and regulation of cognitive processes, employment of strategies, searching for information, and judging and decision making during complex tasks (Engle, Tuholski, Laughlin, & Conway, 1999). Working memory capacity is a well-documented executive ability that has shown to relate strongly to fluid intelligence (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Conway, Kane, & Engle, 2003; Engle et al., 1999; Unsworth & Engle, 2005). In contrast to the unitary storage model of short-term memory, working memory is a multicomponent system, consisting of a storage and an executive attention control component (Baddeley, 2000; Engle et al., 1999). Working memory capacity largely controls the simultaneous storing and processing of information during activities such as the acquisition new knowledge, reading comprehension, and problem solving (Baddeley, 1986; Baddeley & Wilson, 2002; Ericsson & Simon, 1998). It is also believed to influence how successfully people are at overcoming distractions and appropriately shifting attention during complex tasks (Baddeley, 1992, 2000; Conway, Cowan, & Bunting, 2001; Unsworth, Redick, Heitz, Broadway, & Engle, 2009).

Few studies have indirectly investigated the relationship between working memory and creativity, and results suggest that working memory contributes positively to creative thinking. These studies showed that working memory capacity is related to verbal fluency (Daneman, 1991), divergent thinking (Sub et al., 2002), and insight problem solving (DeYoung, Flanders, & Peterson, 2008). More specifically, Sub et al. (2002) tested several structural equation models relating working memory (specified as a storage and processing latent variable and a supervision latent variable) to intelligence (*g* at the apex specified by speed, memory, creativity, and reasoning latent variables). Results indicated that the storage and processing working memory latent variable and the supervision working memory latent variable predicted the creativity factor ($\beta = .39$ and .21, respectively).

Also in support of an executive view of creative thinking, recent research also shows that divergent thinking involves executive processes including strategy selection, category fluency, mental disassembling of figures, alternating between ideation and evaluation, and breaking set in the face of interference (Gilhooly et al., 2007; Khandwalla, 1993; Ruscio, Whitney, & Amabile, 1998). Think-aloud studies of divergent thinking demonstrate that successful divergent thinkers exhibit higher rates of inhibiting common responses and deliberate switching of retrieval cues (Gilhooly et al., 2007), processes believed to engage the central executive component in working memory (Baddeley & Logie, 1999). There is also an indication that executive functions are involved in associative processes. Studies of patients with frontal lobe damage indicate that executive functions are involved in fluently retrieving words that belong to a specified category (e.g., letter F, animals) (Martin, Wiggs, Lalonde, & Mack, 1994; Phillips, 1997).

In sum, there is converging evidence that executive functions, such as working memory, play an important role in creative thinking. Individuals with high working memory capacity are more likely to be successful at overcoming interference caused by automatic, unoriginal responses, and also be more successful at using strategies to generate novel approaches and responses on creative thinking tasks. Increasingly, researchers propose that working memory capacity influences performance on creativity tasks that necessitate cognitive flexibility, higher order rules, and conscious attention to, and manipulation of, a wide range of cues (Damasio, 2001; Dietrich, 2004; Rastogi & Sharma, 2010). While a large body of research investigating the relationship between working memory and intelligence (see Ackerman, Beier, & Boyle, 2005, for a review) as well as the relationship between creativity and intelligence (for reviews, see Barron & Harrington, 1981; Batey & Furnham, 2006; Sternberg & O'Hara, 1999) exists; research investigating the relationship between working memory and creativity has received little attention. Drawing from recent studies that show that creative thinking shares higher-order cognitive processes that reflect facets of general intelligence, another goal of this study was to examine the role of working memory in three types of creative thinking, including associative, divergent, and convergent processes.

Altogether, in the present study, a latent variable analysis was conducted to explore the relationships among intelligence, working memory, and three creative thinking processes: associative fluency, divergent thinking, and convergent thinking. Based on Mednick's (1962) theory of the associative basis of creativity and recent evidence of unique associative processes in creative thinking (e.g., Benedek et al., 2012), we examined whether associative fluency predicted two distinct creative processes: divergent thinking and convergent thinking. Then, drawing from recent research that indicates an important role of intelligence in creativity (e.g., Batey, Furnham, & Safiullina, 2010; Cho et al., 2010; Silvia, 2008a,b; Vincent et al., 2002), we examined the effects of intelligence and working memory (an executive function closely related to *g*) on associative fluency, divergent thinking, and convergent thinking. Finally, a complete latent model including all of the constructs of interest was explored.

5. Method

5.1. Participants

Two hundred and sixty five participants were recruited through an online research participant pool from educational psychology courses at a large southeastern university. The sample consisted of 59 males and 206 females[2]; 60.2% Caucasian, 15.8% Black, 14.7% Hispanic, 6.8% Asian, and 2.3% Other. The average age of the sample was 20.33 years (SD = 2.54). Prior to conducting the study, all study procedures were approved by the university's Institutional Review Board.

5.2. Procedure

Upon arrival at the laboratory, participants were asked to read and sign the informed consent form. Participants then completed a series paper-and-pencil or computer based tasks: intelligence, working memory, creative thinking, and a demographics questionnaire. Participants received course credit for completing the experiment, in partial fulfillment of a course requirement.

5.3. Creative thinking tasks

5.3.1. Associative fluency (AF) tasks

5.3.1.1. Letter fluency task, (Borkowski, Benton, & Spreen, 1967). The letter fluency task was developed to assess phonetic fluency, and requires participants to generate a list of as many words as possible that begin with the letter F (2 min). The total number of appropriate words generated for the letter F was used for the total score.

5.3.1.2. Category fluency tasks (Benton & Hamsher, 1978). The category fluency task requires participants to generate a list of as many different types of animals (2 min) and jobs (2 min) as possible. The total number of appropriate animals and jobs generated was used for the total score. The score on the letter fluency task was moderately correlated with the category fluency scores for name of animals and jobs, $r = .42$, .35, $p < .001$, respectively, providing evidence for convergent validity.

5.3.2. Divergent thinking (DT) tests

5.3.2.1. Guilford's Unusual Uses tests (Guilford et al., 1958). The Unusual Uses test requires participants to develop unusual uses for a common household item (3 min). The item for this task was a wire coat hanger. Participants' responses on the Unusual Uses test were scored using the Snapshot scoring method (Silvia et al., 2008; Silvia, Martin, & Nusbaum, 2009). The Snapshot scoring method gives a set of responses on a divergent thinking test a single holistic rating on a scale of 1 (*not at all creative*) to 5 (*very creative*), producing one score for each person's ideational output (Silvia et al., 2008). Studies employing scoring methods similar to the Snapshot method showed high inter rater reliabilities ranging from .92 to .98 (Runco & Mraz, 1992). There is evidence of good construct reliability, as *H* values representing maximal reliability (the degree to which indicators capture information about the underlying factor) were over .80 for the Snapshot scoring method (Silvia et al., 2009). Snapshot scores have also been shown to relate positively with openness to experience, a personality trait shown to be positively related to creativity (Feist, 1998) ($\beta = .33$), and negatively with conscientiousness, a personality trait shown to be negatively related to creativity ($\beta = -.29$), providing evidence for the concurrent validity of Snapshot scores (Silvia et al., 2009). In this study, the intraclass correlation (ICC) for the reliability across the raters was .77.

5.3.2.2. The Abbreviated Torrance Test for Adults (ATTA; Goff & Torrance, 2002). The ATTA was adapted from The Torrance Tests of Creative Thinking (TTCT; Torrance, 1966, 1974, 2008) and is a widely used measure for assessing divergent thinking (Plucker & Renzulli, 1999). Research reviewing the TTCT provides evidence that it is a valid measure of creative thinking (Kim, 2008). The ATTA contains three 3-minute verbal and figural tasks from the TTCT.

The ATTA is scored on four norm-referenced measures and 15 criterion-referenced indicators (Goff & Torrance, 2002). The four norm-referenced measures include fluency (i.e., number of ideas), originality (i.e., unconventionality or uniqueness of ideas), elaboration (i.e., details or embellishments of ideas), and flexibility (i.e., different types of ideas) (Goff & Torrance, 2002). The fluency, originality, elaboration, and flexibility ratings are summed across the three tasks and converted to a scale that was developed using the conventional stanine scale consisting of a 9-point normalized standard score from 11 (*low*) to 19 (*high*), centered at 15 (Goff & Torrance, 2002). The normalized scaled scores are summed to produce a total scaled score. There are 15 criterion referenced creativity indicators (e.g., richness and colorfulness of imagery, expressions of feelings and emotions, abstractness of titles), each scored on a 3-point scale of 0 (*absence*) to 2 (*two or more present*) (Goff & Torrance, 2002). The composite of total scaled scores from the norm-referenced measures plus criterion-referenced indicators combine to yield a Creativity Index (CI) ranging from 44 to 106. The CI is rescaled and reported as a creativity level ranging from 1 (*minimal*) to 7 (*substantial*) (Goff & Torrance, 2002). Evidence for the predictive and discriminant validity of the ATTA has been reported in recent studies (e.g., Althuizen, Wierenga, & Rossiter, 2010; Kharkhurin & Samadpour Motalleebi, 2008). The norms reported in the ATTA manual are based upon adults who had completed the D-TTCT prior to the year 2000. The manual reports the Kuder–Richardson (KR21) reliability coefficient of .84 for the total raw score for the four creative abilities, and .90 for the total raw score plus the creativity indicators score. Inter-rater reliabilities range from .95 to .99 (Goff & Torrance, 2002). The inter-rater reliability for the creativity indicator score was .96 for the first 100 tasks scored. Because of the high inter-rater reliability, a single rater scored the subsequent tasks. The ICC for the reliability across the raters for the CI score was .98, and for a single rater, .97.

[2] A limitation of this study is the predominantly female sample. Results from studies examining gender differences in creativity are mixed (Kaufman, 2006); however some studies have shown that females score higher on verbal types of creativity tasks (e.g., Kaufman, Niu, Sexton, & Cole, 2010). In our study, no gender differences between males and females were found across the tasks with the exception of the Unusual Uses (wire coat hanger) divergent thinking test ($p < .01$) in which males (M = 2.90, .71) outperformed females (M = 2.59, SD = .67) and the Weschler Adult Intelligence Scale Revised Vocabulary subset ($p < .01$) in which males (M = 60.36, SD = 7.93) also outperformed females (M = 56.39, SD = 9.02).

5.3.3. Convergent thinking (CT) tests

5.3.3.1. Remote Associates Test (RAT; Mednick, 1962; Mednick & Mednick, 1967). The RAT requires participants to identify a solution that is associated with three presented cue words either semantically or through formation of a compound word (e.g., birthday, light, stick, answer: candle). The RAT was developed by Mednick (1962) based on his associative theory of creativity. Mednick and his colleagues provide evidence of both predictive and construct validity of the RAT. Studies have shown that performance on the RAT correlated with faculty ratings of creativity for student architects ($r =$ .70) (Mednick, 1962) and graduate students in psychology ($r =$ .55), and achieving contracts for research proposals in science and engineering domains (Mednick, 1963). Studies also showed that high scores on the RAT were positively and significantly related to measures of associational fluency (Craig & Manis, 1962).

The RAT was computer presented and paced. Participants completed four practice sets, each of which consist of three cue words presented on the screen, followed by a blank screen, where the participant typed in their response. Participants were given up to 15 s per set of 3 cue words before being prompted to generate the fourth word. For the four practice sets, the correct answer was shown following participants' response. After the practice trial, participants completed a set of 30 cue words. The set of cue words was selected from Bowden and Jung-Beeman's (2003) normative data set of 144 compound remote associate problems. The problems were selected and programmed to increase in difficulty as the task progressed. Each correct answer was given a score of 1, for a total possible score of 30 points. Incorrect answers were given a score of 0. Early research investigating the validity of the RAT showed that RAT correlated significantly with ratings of graduate students' research creativity (Mednick, 1963).

5.3.3.2. Insight problems. For the insight problems' task, participants were required to solve two insight problems (i.e. dot problem and word scramble problem) (3 min). In the dot problem, participants were presented with four randomly placed dots. Their task was to connect the four dots using two straight lines without lifting their pencil. The word scramble problem presented a series of randomly ordered letters that formed a common word (i.e., calendar) when properly rearranged.

5.4. Intelligence tests

5.4.1. Raven's Advanced Progressive Matrices (RAPM; Raven, Court, Raven, 1977; Raven, Raven, & Court, 1998)

The short 12-item version of the RAPM (Bors & Stokes, 1998) was used (20 min total). The RAPM is a standardized intelligence test that consists of a series of matrices made up of geometric figures with one section of the matrix missing. Participants are required to identify the correct missing section from a set of eight possible answer choices. Participants completed two practice problems from the RAPM Set I and answers were provided after completion of the two practice problems. Participants were given up to 20 min to complete the short 12-item version from the RAPM Set II (i.e., Items 3, 10, 12, 15, 16, 18, 21, 22, 28, 30, 31, and 34) (Bors & Stokes, 1998). Bors and Stokes (1998) have investigated the short version of the RAPM, revealing satisfactory psychometric properties, including a Cronbach's alpha of .73, correlation with the full length RAPM set II of .92, test–retest reliability of .82, and a moderately strong and statistically significant correlation of −.42 with an information processing task (Bors & Stokes, 1998). In the present study, Cronbach's alpha for the 12 items of the RAPM was of .71 providing evidence for the internal consistency of the measure across the scaled activities.

5.4.2. Weschler Adult Intelligence Scale-Revised, Vocabulary (WAIS-R, Vocab; Weschler, 1958)

The Weschler Adult Intelligence Scale-Revised consists of 11 subtests (6 verbal and 5 performance) that are developed to collectively assess the global intelligence of adults between the ages of 16 to 74. Several factor analytic studies of the WAIS-R showed evidence for separate verbal and nonverbal factors (Anastasi, 1982). Reliability studies showed high reliability coefficients for the verbal, performance, and full scale IQ, ranging from .52 for the Object Assembly subtest to .96 for the Vocabulary subtest (Spruill, 1984). For the purpose of the present study, the Vocabulary subtest of the WAIS-R was used (15 min total). The Vocabulary subtest has shown to correlate highly with verbal IQ (.85) and total IQ (.81) scores (Spruill, 1984). The Vocabulary subtest consists of 35 successive words that increase in degree of unfamiliarity within a normal population. Participants were presented with the list of words, and given up to 15 min to provide as complete of a definition for each word as possible. The present researcher and a research assistant independently scored the Vocabulary subtest. The definition for each word was given a score ranging from 0 to 2. The items were scored according to the rubric in the WAIS-R Tutorial Workbook (Swiercinsky, 1988). The inter-rater agreement was $r =$ .91 and Cronbach's alpha for the 35 items of the WAISR was .88.

5.5. Working memory tasks

5.5.1. Symmetry Span task (SymSpan, Unsworth et al., 2009)

This task requires participants to determine the symmetry of a geometrical picture while simultaneously committing to memory the position of a red square on a 4 by 4 square matrix. Participants were presented with a series of displays on a computer screen. Each display consisted of a geometrical picture, which the participant judged as “yes” it is symmetrical or “no” it is not symmetrical by clicking on the corresponding yes or no button. They were then presented with the 4 by 4 square matrix, in which one of the squares was highlighted in red. After a number of displays had been presented, a recall cue consisting of a blank 4 by 4 square matrix prompted the participants to recall all of the red squares in sequence from the series. The number of displays varied per series from two to six. The total score on the SymSpan was used in the analysis, which represents the total number of squares that were correctly recalled in position.

5.5.2. Backward Digit Span task (Wilde, Strauss, & Tulsky, 2004)

This task requires participants to recall a random sequence of digits in reverse (backwards). Participants were presented with a series of digits, one at a time, on a blank computer screen (e.g., 6, 3, 2, 5). After a series of digits have been presented, a recall cue consisting of a blank rectangular text box prompted the participants to recall of the digits in reverse (e.g., from previous example: 5, 2, 3, 6). The length of the series of digits began with three digits, and increased as the task progressed. The longest series of digits recalled in reverse was the score on the Backward Digit Span task.

6. Results

Mplus 6 was used to explore the relationships among the Working Memory (WM), Intelligence (IQ), Associative Fluency (AF), Divergent Thinking (DT), and Convergent Thinking (CT) latent variables using maximum likelihood estimation with robust errors. The indicators of WM included the total Symmetry Span score (SymSpan) and the score on the Backward Digits task (BackDigit). Indicators of IQ included the total score on the Raven's Advanced Progressive Matrices (RAPMT) and the total score on Weschler Adults Intelligence Scale Revised-Vocabulary subscale (WAISRV). The indicators of AF included the total score on the letter fluency (LetterF) and category fluency tasks (Animals, Jobs). The components of the norm-referenced (ATTAFlu, ATTAOri, ATTAElab, ATTAFlex) and criterion-reference (CRCVerb, CRCFig) scores on the ATTA, and the Snapshot originality (WCHOri) score on the Unusual Uses task were specified as indicators of DT. Indicators of CT included the total score on the Remote Associates Test (RAT) and the score on the dot (InsightDot) and word scramble (InsightWS) insight problems. Descriptive statistics and correlations for the respective scores of all of the indicators are presented in Table 1.

6.1. Three creative thinking processes: Associative fluency, divergent thinking, and convergent thinking

A confirmatory factor analysis (CFA) of the measurement model including the latent variables AF, DT, and CT was conducted. The residual of ATTAFlex was specified to correlate with the residual of ATTAFlu and ATTAElab to improve model fit. Results indicated that the chi-squared test was significant ($\chi^2 = 116.28$, $df = 60$, $p < .001$); however, the chi-squared statistic has been shown to be sensitive to sample size (with larger sample sizes increasing the likelihood of a significant chi-squared test) (Kline, 2005). To overcome this limitation, goodness of fit (GOF) indices were used to assess fit. Results showed that the measurement model was a good fit to the data (RMSEA = .06, CFI = .89, TLI = .86, SRMR = .05) (Hu & Bentler, 1999). The structural model, in which AF predicted DT and CT, was embedded in the measurement model (Fig. 1). The variances of all of the latent variables (in the current and in subsequent analyses) were fixed to 1 for identification. Results provide evidence that AF significantly predicted DT and CT ($\gamma = .56, .82$, $p < .001$, respectively).

6.2. Intelligence and the three creative thinking processes

A model in which IQ was specified to predict the three creative thinking processes, and AF to predict DT and CT was estimated. Results showed that the model was an adequate fit to the data (RMSEA = .07, CFI = .86, TLI = .83, SRMR = .06). IQ significantly predicted AF and CT ($\gamma = .66, .96$, $p < .001$, respectively), but not DT ($\gamma = -.02$, $p = .88$). AF significantly predicted DT ($\beta = .58$, $p < .001$) but not CT ($\beta = -.14$, $p = .41$).

6.3. Working memory and the three creative thinking processes

A model in which WM was specified to predict the three creative thinking processes (i.e., AF, DT, and CT), and AF to predict DT and CT was estimated. Results showed that the model did not meet the criteria for good fit (RMSEA = .05, CFI = .91, TLI = .89, SRMR = .05). WM significantly predicted AF and CT ($\gamma = .47, .66$, $p < .001$, respectively), but not DT ($\gamma = -.14$, $p = .34$). AF significantly predicted DT ($\beta = .63$, $p < .001$) but not CT ($\beta = .37$, $p = .07$).

6.4. The relationships among intelligence, working memory, and the three creative thinking processes

To assess the relationships among intelligence, working memory, and creative processes, a measurement model including IQ, WM, and the three creative processes was estimated. The model was a good fit to the data (RMSEA = .05, CFI = .89, TLI = .86, SRMR = .06). Excluding the insignificant paths from the models above, a complete model that specifies WM as a predictor of IQ, AF, and CT, and IQ as a predictor of AF and CT, and finally AF as a predictor of DT was estimated. The model was an adequate fit to the data (RMSEA = .06, CFI = .87, TLI = .84, SRMR = .06). Results showed that WM significantly predicted IQ ($\gamma = .73$, $p < .001$), but not AF ($\gamma = .01$, $p = .96$) or CT ($\gamma = .05$, $p = .77$). IQ was a significant predictor of AF ($\beta = .62$, $p < .01$) and CT ($\beta = .91$, $p < .001$). Finally, AF was a significant predictor of DT ($\beta = .55$, $p < .001$). The indirect path from IQ to DT through AF was also significant ($\beta = .28$, $p < .01$).

Given that WM only predicted IQ, the non-significant parameters were deleted and the final structural model that specifies WM as a predictor of IQ, IQ as a predictor of AF, and AF as a predictor of DT and CT was estimated (Fig. 2). The theoretical rationale for this model draws from the well-documented evidence of working memory as a strong predictor of IQ (e.g., Conway et al., 2002; Kyllonen & Christal, 1990) combined with our proposed model of the relationships among three creative thinking processes in which associative fluency predicts divergent thinking and convergent thinking. Based on recent studies that show intelligence to be a strong predictor of creative thinking (e.g., Nusbaum & Silvia, 2011) and established theories of the associative basis of creative thought (Mednick, 1962), this model proposes that intelligence predicts associative fluency directly, and indirectly predicts divergent and convergent thinking abilities through associative fluency. Results provide evidence that the model was an adequate fit to the data (RMSEA =.06, CFI = .82, TLI = .79, SRMR = .06). WM significantly predicted IQ ($\gamma = .70$, $p < .001$), and indirectly predicted AF, DT, and CT ($\gamma = .59, .32, .54$, $p < .001$, respectively). IQ was a significant predictor of AF ($\beta = .84$, $p < .001$), and an indirect predictor of DT and CT through AF ($\beta = .46, .77$, $p < .001$). Finally, AF was a significant predictor of both DT ($\beta = .55$, $p < .001$) and CT ($\beta = .92$, $p < .001$).

Table 1
Descriptive statistics and correlations of observed variables.

	M	SD	Min, max	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. BackDigit	5.67	1.55	0.9	1																
2. SymSpan	27.13	8.73	4, 41	.229**	1															
3. RAPM	6.74	2.67	0, 12	.222**	.291**	1														
4. WAISRV	57.27	8.93	23, 70	.282**	.118	.221**	1													
5. LetterF	23.10	5.50	9, 40	.225**	.094	.185**	.303**	1												
6. Animals	26.99	5.79	12, 45	.189**	.107	.150*	.334**	.424**	1											
7. Jobs	21.06	4.55	9, 32	.175**	.091	.069	.289**	.345**	.434**	1										
8. ATTAFlu	15.86	2.24	10, 19	−.016	.043	.032	.190**	.190**	.211**	.180**	1									
9. ATTAOri	15.21	2.35	8, 19	−.022	.029	−.083	−.017	.185**	.089	.133*	.194**	1								
10. ATTAEla	15.90	2.35	6, 19	.047	.010	.138*	.173**	.256**	.195**	.266**	.339**	.236**	1							
11. ATTAFlex	15.32	2.29	1, 19	.070	.034	.234**	.162**	.115	.126*	.051	.509**	.022	.378**	1						
12. CRCVer	2.06	1.19	0, 8	.121	−.018	.038	.242**	.092	.174**	.120	.390**	.252**	.219**	.177**	1					
13. CRCFig	5.85	2.53	0, 13	.122	.047	.057	.202**	.253**	.221**	.308**	.225**	.418**	.507**	.103	.357**	1				
14. WCHOri	2.66	.69	1, 5	.057	.122	.093	.181**	.215**	.190**	.231**	.110	.141*	.205**	−.026	.025	.161**	1			
15. RAT	16.37	5.22	2, 28	.255**	.129*	.324**	.404**	.222**	.212**	.145*	−.031	−.117	.076	.071	.071	.153*	.063	1		
16. InsightDot	.30	.46	0, 1	.170**	.157*	.273**	.245**	.079	.162**	.082	.096	.096	.138*	.094	.153*	.096	.114	.131*	1	
17. InsightWS	.20	.40	0, 1	.071	.078	.042	.159*	.153*	.085	.156*	.066	.095	.043	−.088	−.002	.192**	.058	.074	.018	1

BackDigit = Backward Digit Span, SymSpan = Symmetry Span, RAPM = Raven's Advanced Progressive Matrices, WAISRV = Weschler Adult Intelligence Scale Revised Vocabulary subset, LetterF = Letter fluency task, Animals = Category fluency task (Animals), Jobs = Category fluency task (Jobs), ATTA = Abbreviated Torrance Test for Adults (Flu = Fluency, Ori = Originality, Elab = Elaboration, Flex = Flexibility, scaled scores), CRC = Criterion Referenced Creativity Indicators (Ver = Verbal, Fig = Figural), WCHOri = Unusual Uses task Originality, RAT = Remote Associates Test, InsightDot = Dot Problem, InsightWS = Word Scramble.

* $p < .05$.

** $p < .01$.

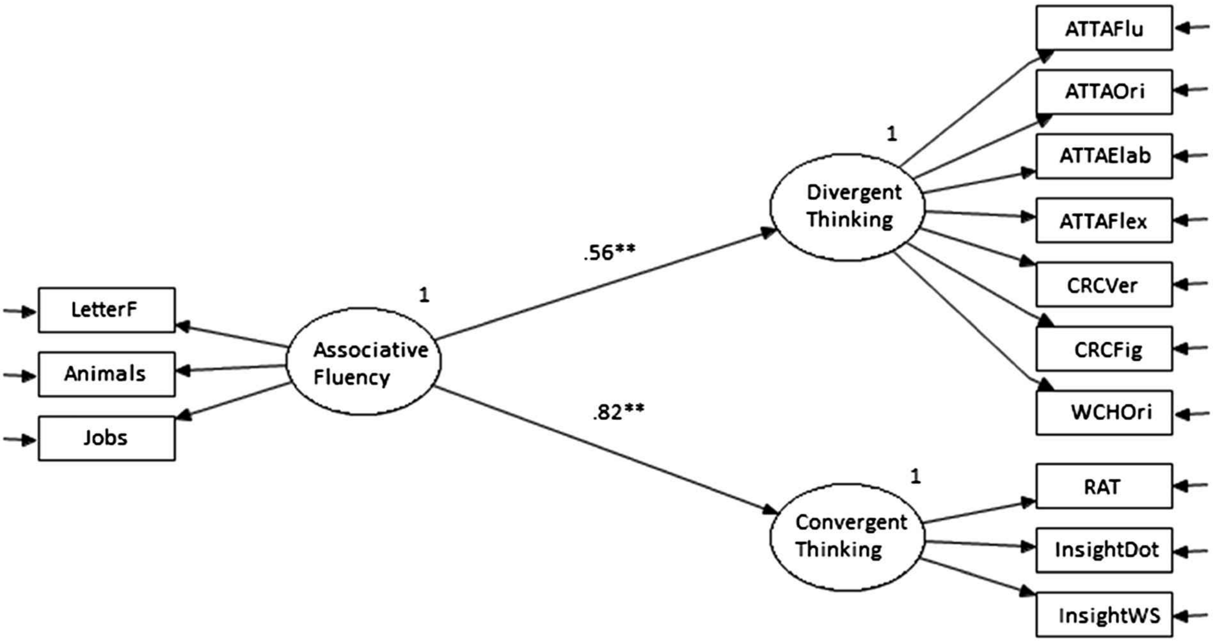

Fig. 1. The relationships among associative fluency, divergent thinking, and convergent thinking. $^{*}p < .05$, $^{**}p < .01$.

7. Discussion

One of the aims of this study was to explain the relationships among intelligence and creative thinking processes. To this end, we first modeled the relationships among three types of creative thinking processes (i.e., associative fluency, divergent thinking, and convergent thinking), followed by an examination of how intelligence and working memory predict these creative processes.

7.1. Associative fluency predicts both divergent thinking and convergent thinking

In our model, associative fluency was a significant predictor of *both* divergent thinking and convergent thinking. These results mirror Benedek et al.'s (2012) work demonstrating that associative abilities (i.e., associative fluency, flexibility, dissociation, and combination) explained nearly half of the variance of divergent thinking ability. In addition, our findings extend that

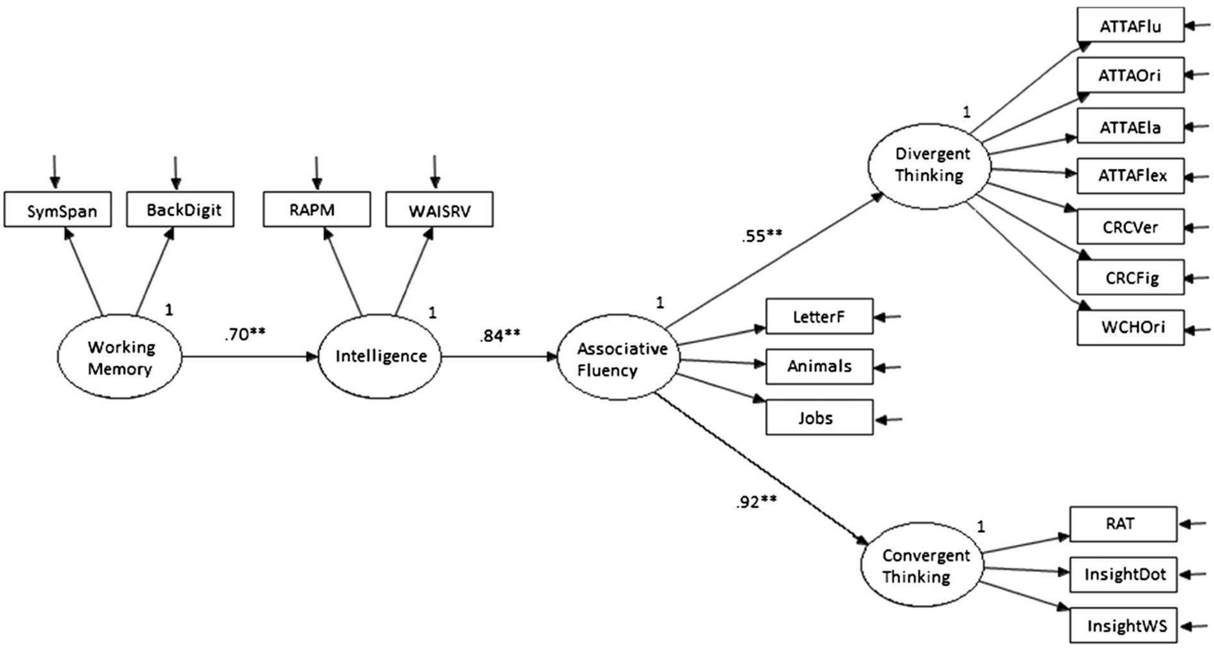

Fig. 2. The relationships among working memory, intelligence, associative fluency, divergent thinking, and convergent thinking. $^{*}p < .05$, $^{**}p < .01$.

line of research by providing evidence that associative fluency is also a significant predictor of convergent thinking.

The significant relationships found between associative fluency and both divergent thinking and convergent thinking are noteworthy particularly because divergent thinking and convergent thinking emerged as two distinct types of creative thinking. Results from our study showed that almost all the indicators of divergent thinking were either weakly or insignificantly correlated with scores on convergent thinking tasks. For example, the creativity index on the ATTA had a correlation of $r = .09$, *ns*, with the total score on the RAT. Similarly, fluency, originality, elaboration, and flexibility scores on the ATTA were weakly correlated with the RAT score ($r = -.03$, $-.12$, .08, and .17, *ns*, respectively). Furthermore, in the final model (Fig. 2), the divergent and convergent thinking latent variables were also not related ($-.52$, *ns*). Overall, the patterns of relationships found among associative fluency, divergent thinking, and convergent thinking suggest that associative fluency is a cognitive process that is shared by divergent (the generation of novel and unusual ideas) thinking and convergent (the combination of distally related ideas to identify a correct solution) thinking. These findings lend empirical evidence to Mednick's (1962) theory of the associative basis of creativity, which proposed that associative abilities, including the ability to activate, retrieve, and combine associations, are an important feature of creative (both divergent and convergent) thinking.

7.2. Intelligence and creative processes

In addition to examining the longstanding view that associative processes underlie creative thinking, we also explored the role of intelligence in three creative processes (i.e., associative fluency, divergent thinking, and convergent thinking). Using as context the early works of Mednick (1962) and Mendelsohn (1976) suggesting individual differences in associative processing, as well as more contemporary studies demonstrating a link between intelligence and divergent thinking (e.g., Nusbaum & Silvia, 2011; Silvia, 2008a,b; Vincent et al., 2002), we proposed that intelligence predicts associative fluency, divergent thinking, and convergent thinking.

We first found that intelligence directly predicts associative fluency and convergent thinking, but not divergent thinking. In another model, results showed that intelligence indirectly predicted divergent thinking and convergent thinking through associative fluency. In the latter model, intelligence was a strong predictor of associative fluency ($\beta = .85$), and associative fluency was then a strong predictor of convergent thinking ($\beta = .92$) (but also predicted divergent thinking). In both models, intelligence was a stronger predictor of associative fluency and convergent thinking. These patterns of relationships are also reflected in the significantly positive correlations found between performance on the RAT (a widely used convergent test of creativity) and measures of intelligence (i.e., RAPM, WAISRV) as well as between the RAT scores and scores on the working memory tasks (i.e., SymSpan, Backward Digit span). Our results support earlier findings (e.g., Jacobson et al., 1968, Taft & Rossiter, 1966) that showed that the RAT correlates more highly with traditional tests of convergent thinking compared to measures of divergent thinking. Although our results showed that intelligence indirectly predicted divergent thinking through associative fluency, the paths among these latent constructs were not as strong as the paths from intelligence to convergent thinking. A possible explanation for these findings is that because intelligence, executive, and convergent creativity tests consist of complex tasks that rely more heavily on analytic cognitive processes, tests such as the RAT and insight problems are more closely related to intelligence, traditionally defined, compared to divergent thinking tests.

Taken together, our findings lend evidence to recent studies that indicate that intelligence is a relevant construct in creative thinking, particularly for the ability to activate and retrieve a large amount of ideas from memory (i.e., associative fluency) and the ability to identify the correct answer to problems for which the path to the solution was ambiguous (i.e., convergent thinking). Regarding the role of intelligence on divergent thinking, results were mixed; intelligence did not directly predict divergent thinking, but emerged as an indirect predictor through associative fluency. It seems that when other creative thinking processes are taken into account (i.e., associative and convergent processes), the relationship between intelligence and divergent thinking is weak. However, this is the first known study to investigate the contribution of intelligence on three creative processes simultaneously, and future validation studies are needed to support our claims.

7.3. Working memory and creative processes

Many explanations for the ways in which intelligence is relevant for creative processes have been suggested by researchers, including attentional control (Mendelsohn, 1976), interference management (Gilhooly et al., 2007), and strategy application (Nusbaum & Silvia, 2011). Research exploring possible executive functions in creativity has focused almost entirely on performance on divergent thinking tasks, showing compelling evidence that creative ideation requires overcoming interference caused by common responses (Gilhooly et al., 2007; Kane, Bleckley, Conway, & Engle, 2001; Silvia, 2008a,b). In this study, we directly examined the role of an executive function, working memory, on creative thinking. We found empirical evidence that working memory may play a role in divergent thinking, associative fluency, and convergent thinking. Similar to the relationships among intelligence and the three creative thinking processes, results showed that working memory significantly predicted associative fluency and convergent thinking, but not divergent thinking. In the combined model, working memory indirectly predicted all three creative processes through intelligence and associative fluency.

In divergent thinking tests, working memory is likely to provide an advantage in being able to generate and consider several different ideas while simultaneously selecting the most original and ignoring the more obvious responses. This ability to switch between response categories has been shown to predict better performance on divergent thinking tests (e.g., Benedek et al., 2012; Gilhooly et al., 2007; Nusbaum & Silvia, 2011). In the case of convergent thinking tasks such as the RAT and the insight problems, working memory may play an important role in people's ability to break away from a mental set or an ineffective approach to the problem. In fact, Mendelsohn (1976) argued early on that high performance on the RAT is due to “greater breadth of attention deployment with respect to external cues” and an increased ability to "maintain several streams of cognitive activity simultaneously" (p. 347)—cognitive mechanisms that align closely with components of Baddeley's (1986) model of working memory developed a decade later. Finally, set shifting advantages linked to greater working memory capacity are also likely to support performance on the letter and category fluency (i.e., associative) tasks, by allowing people to attend to a wider set of semantic and taxonomic categories that are available via spread of activation. This study contributes to the existing findings regarding the intelligence–creativity link, by explicitly providing evidence that working memory, an executive function closely related to *g*, also benefits performance on creative thinking tasks.

8. Implications and future directions

Following the experimental work of Gestalt psychologists, the psychometric approach to studying creativity via divergent thinking tests is often credited to Guilford's (1950) American Psychological Association Presidential Address. As divergent thinking tests gained popularity, they were increasingly used as global tests of creative ability, despite some researchers concerns that this method misrepresents creativity as a monolithic entity (Arden et al., 2010; Dietrich, 2004; Runco, 1999). The predominance of divergent thinking tests in the creativity literature is surprising, considering the numerous theoretical propositions and rich philosophical perspectives that have been offered regarding the possible range of cognitive processes that underlie creativity (e.g., Carroll, 1993; Finke et al., 1992; Guilford, 1967; Mednick, 1962; Wallas, 1926). This study begins to address these concerns by exploring the relationships among several cognitive abilities and processes related to creativity. We provide evidence for the associative underpinnings of divergent thinking and convergent thinking. Additionally, we provide evidence that intelligence and working memory are significant predictors of performance on a range of creative thinking tasks.

These findings have meaningful implications for theoretical frameworks of creative cognition. In the literature, divergent thinking is described as an inductive process related to idea generation and convergent thinking is commonly characterized as a deductive process related to searching for a single, correct solution (Guildford, 1957; Brophy, 2000). Results from this study provide some of the first empirical evidence that divergent thinking and convergent thinking, assessed by commonly used creative thinking tests, tap distinct cognitive mechanisms. In addition, results from this study indicate that associative fluency may be a broader cognitive mechanism that these two distinct types of creative thinking share. Altogether, we propose a model of creative cognition that specifies associative fluency as an important underlying component of divergent thinking and convergent thinking. Future research is needed to explore how different associative processes (e.g., fluency, flexibility, disassociation, and combination, Benedek et al., 2012) contribute to divergent thinking and convergent thinking. Parsing broad cognitive processes involved in creativity into specific, observable sub processes, and examining the relationships among them, are important steps towards gaining a more nuanced understanding of creative thinking. In this way, the psychometric study of creativity can move beyond the use of divergent thinking tests as proxy for creativity, and move towards a more comprehensive study of how individuals perform on multiple tasks that tap into various creative processes.

Future research is also needed to explore how the three creative thinking processes identified in this study contribute to real-life creative behaviors and achievements. Most of the work examining the predictive validity of creativity tests has focused on the relationships between divergent thinking performance and self-report surveys of creative behaviors and accomplishments (Hocevar, 1979; Runco, 1999; Silvia et al., 2008). In contrast, the relationship between convergent thinking and real-life creativity has not been empirically investigated. Models of creative cognition (e.g., Finke et al.'s, 1992 Geneplore Model) and creative problem solving (e.g., Isaksen, Dorval, & Treffinger, 2000; Treffinger, 1995; Wallas, 1926) propose that creativity is facilitated by a divergent thinking phase where ideas are freely generated, followed by a convergent thinking phase in which ideas are carefully evaluated, chosen, and developed. Anecdotal evidence from case studies of eminent individuals provides some preliminary evidence for these models of creative thinking (Becker, 1995; Galton, 1962); however, empirical studies examining the link between creative thinking processes and actual creative performance are needed.

In line with findings reported by contemporary creativity researchers, we found evidence that intelligence and working memory play an important role in creative thinking. Recasting creative thinking as a higher-order cognitive process, and further exploring the conditions for fostering creativity (e.g., Dietrich & Kanso, 2010; Gilhooly et al., 2007; Nusbaum & Silvia, 2011), is a fruitful approach to better understand the cognitive underpinnings of creative thought. An executive interpretation of creative thinking opens new lines of research to investigate how the acquisition and implementation of higher-order cognitive processes (critical in learning and problem-solving), may also explain individual differences in creativity. In addition to further exploring the role of working memory in creative thinking, much remains to be studied regarding the relative contributions of different types of intelligence (e.g., crystallized versus fluid), domain knowledge, strategy use, metacognitive processes, and other executive functions on creativity. This line of study is also likely to shed light on how intelligence and creativity involve distinct and unique processes, providing more nuanced information on the nature of the relationship between these two complex constructs. By examining individual cognitive processes using advanced statistical methods and tools of cognitive science, there are many opportunities to continue rigorous investigations of the roles of individual difference factors in various creative thinking processes.

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