Abstract

Increasing research efforts are focused on explaining the cognitive bases of creativity. However, it remains unclear when and how cognitive factors such as intelligence and executive function uniquely contribute to performance on creative thinking tasks. Although a relationship between fluid intelligence (*Gf*) and creative cognition has been well-documented, the underlying mechanism of this relation is unknown. Here, we test one possible mechanism of the Gf–creativity association—attention control (AC)—given AC's strong association with Gf and its theoretical relevance to creative cognition. We also examine the role of mind wandering (i.e., task-unrelated thought), a failure of AC that is potentially beneficial to creativity. Using latent variable and bifactor models, we investigated the unique contributions of AC to divergent thinking—above the influence of *Gf*—evaluating the specific and general contributions of AC, *Gf*, and mind wandering to divergent thinking. We found that a general executive factor (i.e., of the common variance to AC, mind wandering, and *Gf* indicators) significantly predicted divergent thinking originality ($\beta = .40$, $p < .001$) above and beyond specific *Gf* and mind wandering factors. Importantly, in the bifactor model, mind wandering was a nonsignificant, negative predictor of divergent thinking performance, and the residual effects of *Gf* were no longer significant, indicating that the relationship between *Gf* and divergent thinking is explained by shared variance with a common executive attention factor. This study provides novel evidence suggesting that the relationship between *Gf* and divergent thinking may be largely driven by the top-down control of attention.

Keywords: creative cognition, divergent thinking, executive attention, intelligence, mind wandering

Keeping Creativity Under Control:

Contributions of Attention Control and Fluid Intelligence to Divergent Thinking

Modern society is constantly evolving, demanding that people think creatively to respond adaptively in the face of unprecedented challenges. Given the importance of creativity to everyday problem-solving and social advancement, the cognitive basis of creative thinking has been of increasing interest. An ongoing controversy in creativity research concerns fluid intelligence (*Gf*). Although several studies have demonstrated a link between *Gf* and divergent creative thinking (Akhtar & Kartika, 2019; Batey et al., 2010; Beaty, Nusbaum, & Silvia, 2014; Beaty, Silvia et al., 2014; Benedek et al., 2012; Benedek, Jauk, Sommer et al., 2014; Cho et al., 2010; Furnham et al., 2005, 2008; Karwowski et al., 2016; Kenett et al., 2016; Liu et al., 2019; Nusbaum & Silvia, 2011; Preckel et al., 2006; Silvia, 2008; Silvia & Beaty, 2012; Silvia, 2015; Sligh et al., 2005), the underlying mechanism of this relation remains unclear. Given the strong overlap between *Gf* and working memory (Brewin & Beaton, 2002; Burgess et al., 2011; Conway et al., 2002, 2003; Engle & Kane, 2004; Chuderski, 2013; Engle, Tuholski et al., 1999; Fukuda et al., 2010; Kane & Engle, 2002; Kane et al., 2004, 2005), one possibility is that the intelligence–divergent thinking relation reflects variation in the executive control of attention—the ability to strategically direct attention and cognition to solve problems (Eslinger, 1996; Zelazo et al., 2004). Yet creative thinking has also been connected to mind wandering, which may be considered the antithesis of attention control (Kane & McVay, 2012; McVay & Kane, 2009, 2010, Smallwood & Schooler, 2006; Thomson et al., 2015). The purpose of the present study was to investigate the unique relation between attention control and divergent thinking, above the influence of *Gf*. We also examined whether individual differences in mind-wandering during ongoing tasks (i.e., task-unrelated thoughts; TUTs) were associated with people's ability to think creatively.

Cognitive Theories of Creativity

Creativity research often measures divergent thinking as an indicator of creative potential (Runco & Acar, 2012). Divergent thinking assessments require people to generate a variety of uncommon, original ideas from a single prompt or stimulus. For example, the Alternative Uses Task (Guilford, 1967) prompts responses that focus on novel ways to use an everyday object that differ from normal uses. This task is

thought to capture elements of creative cognition because, unlike standard problem-solving (e.g., matrix reasoning), the goal is to produce task-appropriate solutions that differ from what anyone has thought of before (Sawyer, 2006; Silvia et al., 2008). That is, the cognitive processes of creative ideation are perhaps more ambiguous than other mental operations because there is no definitive "right" way to think. In fact, the criteria often used to appraise divergent thinking quality hinges on determining whether a given response is subjectively clever or surprising, remote (i.e., distantly associated with standard response candidates), and rare or uncommon (Amabile, 1982; Silvia et al., 2008). For individuals to successfully generate high-quality ideas and solutions, they must not only grapple with ambiguity in the creative problem-solving process, but they also must overcome the threat of mentally fixating on prior knowledge and experiences (Jansson & Smith, 1991; Wiley, 1998).

The *associative theory* of creativity posits that individual differences in creative thinking relate to variation in the organization of concepts in semantic memory (Mednick, 1962). According to this theory, the creative thought process becomes disrupted when people activate salient but unoriginal semantic representations. Thus, less-creative people tend to be constrained by strong, close associates to a target stimulus, whereas highly creative people can overcome such constraints and establish remote conceptual combinations (Kenett & Faust, 2019). Several studies have used network science methods to empirically validate this claim, finding that more creative people have a more "flexible" semantic network structure marked by short paths (distances) and high connectivity between concepts (Benedek et al., 2017; Gray et al., 2019; Kenett et al., 2014, 2018; Kenett & Faust, 2019). The associative theory of creativity therefore highlights a critical feature of the creative thought process—semantic interference—positing that the *structure* of knowledge plays a key role in bypassing interfering concepts (Beaty et al., 2017).

Another line of research has examined the *processes* that operate on the structure of semantic networks, emphasizing a role of controlled attention. The *controlled-attention theory* of creativity asserts that creative thinking depends on top-down attentional control (Beaty, Silvia et al. 2014; Benedek et al., 2012; Jauk et al., 2014). Attention control is core component of executive function, which is an overarching term that incorporates various complex control processes responsible for regulating goal-directed thought

and behavior (Eslinger, 1996; Zelazo et al., 2004), especially during effortful, novel tasks (Banich, 2009; Engle & Kane, 2004; Kane et al., 2001; Kane & Engle, 2002; Kane & McVay, 2012; Lezak et al., 2004; Miyake & Friedman, 2012). In the context of creativity, successful attention control may permit access to a wider variety of remote, original ideas, by directing the creative thought process away from strong, common associates. For example, although the stimulus item "shoe" may initially activate close associates (e.g., walking, running, etc.), uncommon associates to "shoe" may be activated, or otherwise made accessible (e.g., bucket, glove, etc.), when attention is focused on inhibiting salient, yet unoriginal responses (Beaty et al., 2017; Cassotti et al., 2016). In this case, controlled attention may redirect and drive search processes by intervening in an otherwise spontaneous process of spreading activation within semantic memory networks.

Intelligence and Creativity

The controlled attention theory of creativity has received support from research on intelligence and creative thinking. Cattell (1971) proposed that creativity emerges as a function of general intelligence, with *Gf* likely playing the most prominent role in creative thinking because it is characterized by the ability to adapt to novel circumstances and solve problems using complex reasoning. In addition, *Gf* is thought to facilitate the manipulation and selection of task-relevant concepts among competing mental representations elicited during divergent thinking tasks (Batey et al., 2009; Shipstead et al., 2016). In this way, relationships between *Gf* and divergent thinking may reflect effective regulation of top-down executive control (Beaty & Silvia, 2012; Beaty, Silvia, et al., 2014). The structure of knowledge appears to passively influence creative idea generation per the associative theory (Mednick, 1962); however, controlled-attention processes, which are associated with *Gf* (Engle et al. 1999), are thought to actively influence creative thinking by promoting inhibition of initial, less-creative response options (Beaty & Silvia, 2012), shifting across multiple semantic categories (Beaty, Silvia et al., 2014; Nusbaum & Silvia, 2011), and updating information in working memory to satisfy task demands (Engle et al., 1999). Relatedly, Nusbaum and Silvia (2011) argued that (1) *Gf* is central to identifying strategies for inhibiting or shifting thought away from standard responses and (2) executive control is central to implementing these strategies to generate more

novel ideas during divergent thinking. Latent variable analysis demonstrated that executive switching ability mediated the link between *Gf* and divergent thinking (Nusbaum & Silvia, 2011). That is, *Gf* predicted divergent thinking performance, and individuals with higher *Gf* were better able to use executive strategies to combat response interference when generating novel ideas.

An executive-ability approach may also provide insight into the role *Gf* plays in information processing and updating under temporal constraints during divergent thinking (Batey et al., 2010). For instance, Beaty and Silvia (2012) found that, during a ten-minute divergent thinking task, subjects with higher *Gf* did not exhibit the serial-order-effect, which occurs when responses are less creative at the beginning of the testing period but become more creative over time (Christensen et al., 1957; Parnes, 1961; Ward, 1969). One plausible explanation for this outcome is that *Gf* may be an effective governor of higher-order cognition from the onset of creative thinking, such that more time is not needed to successfully inhibit conventional ideas because attention can be rapidly directed towards less salient responses throughout the problem solving process (Beaty & Silvia, 2012). Benedek, Jauk, Sommer, and colleagues (2014) offer preliminary support for an attention control explanation, finding that working memory capacity (controlled attention to actively maintain and manipulate task-relevant concepts; Engle, 2002; Kane et al., 2001) attenuated the shared variance between latent *Gf* and divergent thinking ability by 43%. The authors concluded that the intelligence–creativity relationship appears to be uniquely impacted by executive control over the goal-directed search for, and strategic retrieval of, remote ideas (Benedek, Jauk, Sommer et al., 2014). Furthermore, research outside of creativity has shown that the contribution of executive attention to working memory is a predictive mechanism of *Gf* in latent-variable analyses (Draheim et al., 2020; Oberauer et al., 2005; Shipstead et al., 2014; Süss et al., 2002). Taken together, evidence points to the possibility that top-down executive processes may underlie the relationship between intelligence and creative ideation (Beaty et al., 2017; Beaty & Silvia, 2012; Nusbaum & Silvia, 2011), but specific mechanisms remain unclear. Given the link between controlled attention and intelligence, and controlled attention and creative thinking, we sought to investigate whether attentional control may drive the *Gf*–creative cognition relationship.

Creative Cognition and Attention Control

Executive control processes are proposed to underlie the association between *Gf* and creativity (Benedek, Jauk, Sommer et al., 2014). This is because Gf involves cognitive functions that work together to actively maintain and update information in working memory so that effortful, goal-directed behavior can be executed (Heitz et al., 2006; Kane & Engle, 2002). These mental abilities are generally attributed to frontal lobe networks (McCabe et al., 2010; Miyake et al., 2000; Phillips & Della Sala, 1998), and their interplay is posited to represent a common executive attention mechanism (McCabe et al., 2012; Shallice et al., 1993) that relies heavily on working memory (McCabe et al., 2000) and is strongly associated with intelligence (Engle, 2018; Engle & Kane, 2004; Kane & Engle, 2002).

In order to override the habit of responding conventionally during creative thinking, strategy maintenance and manipulation of task stimuli in working memory may be essential (Lee & Therriault, 2013; Nusbaum & Silvia, 2011). Working memory fulfills two basic functions: to keep novel information available for active processing and to discriminate between task-relevant and task-irrelevant information (Engle & Kane, 2004; Engle et al., 1999; Unsworth & Engle, 2007). However, the role of working memory and executive control for creative cognition has not been empirically clarified, with some authors reporting evidence for a positive relation (Beaty & Silvia, 2012; Benedek, Jauk, Sommer et al., 2014; De Dreu et al., 2012; Dygert & Jarosz, 2020; Gilhooly et al., 2007; Nusbaum & Silvia, 2011; Oberauer et al., 2008; Süss et al., 2002) and others failing to observe an association (Furley & Memmert, 2015; Jarosz et al., 2012; Lin & Lien, 2013; Moraru et al., 2016; Wiley & Jarosz, 2012; Smeekens & Kane, 2016). It is possible that executive attention, as indicated by working memory, is not always positively related to creative cognition because strategically defocusing attention may allow for unconstrained mental access to remote ideas (Zabelina et al., 2016; Zabelina & Robinson, 2010). Shifts to defocused attention may also unfold in a less strategic manner during creative thinking, meaning that attention regulation is not always a goal-directed process. Attention is influenced by other cognitive factors, such as inhibitory control (Martindale, 2007) and/or the efficiency of forging spontaneous associations among concepts in semantic memory (Kenett et al., 2014, 2018; Kenett & Faust, 2019; Gabora, 2018b). Semantic memory networks have been proposed to

scaffold the development of new connections between distributed, unrelated concepts in a self-organizing process that oscillates between focused, analytic thought to more defocused, associative thought (Gabora, 2017; 2018a, 2018b). Taken together, too much attentional control may restrict the ability to mentally explore the boundaries of semantic space, thereby preventing an expansive search for distant associates during divergent thinking (Jarosz et al., 2012; White & Shah, 2006). Therefore, some theorists have emphasized the utility of mind-wandering for facilitating creative cognition (Baars, 2010; Fox & Beaty, 2019; Schooler et al., 2011; Smallwood & Schooler, 2006; Smith et al., 2020).

Mind wandering—particularly in the form of task-unrelated thought (Seli et al., 2018)—may sometimes result from a failure of controlled attention, although mind wandering has been favorably linked with creative thinking performance in some studies. Relaxing attentional control may benefit creativity when mind wandering occurs within a non-demanding incubation period, which is essentially a planned break during problem-solving (Baird et al., 2012; Sio & Ormerod, 2009), or during open-monitoring meditation, which encourages intentional distribution of attention to freely experience incoming sensations and thoughts without judgment (Colzato et al., 2012; Lebuda et al., 2016). However, mind wandering events have also been linked to lower executive control ability and may occur during both easy and challenging tasks (Kane et al., 2007; McVay & Kane, 2010; Randall et al., 2014; Unsworth et al., 2012). This is because task-unrelated thought (TUT), may be indicative of executive control failures, as task-irrelevant stimuli occupy critical executive attention resources (Kane & McVay, 2012; McVay & Kane, 2010, 2012a; Schooler et al., 2011; Smallwood & Schooler, 2006; Smeekens & Kane, 2016) and attention shifts from the goals of the target task to an individual's internal environment (Levinson et al., 2012). Because attention guides the content of conscious experience, it is plausible that it also guides the content of goal-directed creative thought (Smeekens & Kane, 2016). Attention allocated to auxiliary goals may therefore reflect goal-neglect during creative problem-solving. However, mixed findings on the mind wandering–creativity relationship warrant further exploration (e.g., Baird et al., 2012; Gable et al., 2019; Hao et al., 2015; Smeekens & Kane, 2016).

The Present Research

Cognitive abilities, such as fluid intelligence and executive attention, likely play essential roles in creative thinking. However, little is known about how, and under what circumstances, such controlled cognitive abilities uniquely relate to performance on divergent thinking tasks. Some evidence suggests that the shared variance between *Gf* and divergent thinking may be accounted for by specific executive functions (e.g., updating; Benedek, Jauk, Sommer et al., 2014), but the role of attention control in creative cognition remains controversial (Smeekens & Kane, 2016). The present research takes a unique approach to modeling executive attention as a potentially stronger predictor of creative cognition than *Gf*-specific and TUT-specific factors. Executive attention can be conceptualized as a higher-order cognitive construct that incorporates many varieties of controlled, top-down mental activity. We contend that executive attention may regulate creative cognition such that individuals are able to adopt self-regulated, reasoned strategies for generating original ideas (Beaty & Silvia, 2012, 2013; Benedek, Jauk, Sommer et al., 2014; Nusbaum & Silvia, 2011; Silvia, 2015). Additionally, given mixed findings within the mind wandering literature, TUTs during executively-demanding tasks may either benefit or disrupt creative cognition (cf., Agnoli et al., 2018). To this end, we hypothesized that individual differences in executive attention would uniquely predict divergent thinking performance and would also help explain the relationship between *Gf* and divergent thinking.

Method

Participants

This study was approved by the institutional review board at the University of North Carolina at Greensboro and participants provided written informed consent before any data collection began. Determination of sample size was based on the typical structural equation modeling sample sizes utilized in latent variable studies within the creativity literature (e.g., Silvia et al., 2013), and was also constrained by grant funding. The total sample was comprised of 186 adults (129 women, mean age = 22.74 years, *SD* = 6.37), recruited as part of a larger study measuring individual differences in creative cognition and receiving up to $100 depending on the amount of time invested across several laboratory and ecological research activities (see Beaty et al., 2018; Maillet et al., 2018); the executive attention tasks were administered on

the final day of the study, and some participants did not return to complete these tasks (n = 17), yielding a reduced sample of 169 for only the executive attention analysis. Participants were excluded from the study if they reported a history of diagnosed neurological disorder, cognitive disability, or current use of medications known to affect the central nervous system. Participants completed neuroimaging and behavioral tasks during two laboratory phases. The first phase consisted of an fMRI task protocol and several behavioral assessments, and the second phase involved completion of the remaining behavioral assessments. The fMRI protocol included divergent thinking with recorded verbal responses; here, we present the behavioral performance but not the fMRI data (see Beaty et al., 2018; Frith et al., 2020).

Divergent Thinking Assessments

fMRI task procedures. Participants completed a divergent thinking AUT (23 experimental trials) and an object characteristics task (OCT; 23 control trials; not analyzed here) to facilitate event-related fMRI measurement of creative cognition. The AUT required thinking of a creative use for a common object, and participants were instructed to "be creative" and "to come up with something clever, humorous, original, compelling, or interesting" (Beaty, Silvia et al., 2014; Nusbaum et al., 2014). In contrast, the OCT required semantic recall and participants were instructed to think of prototypical characteristics of common objects. For more on the specific task procedures, see Beaty et al. (2015) and Fink et al. (2009). During each of the 46 total trials, participants were first shown a jittered fixation cross (4-6 s), followed by a cue that signaled whether the next trial would be an AUT or OCT trial (3 s). Next, the prompt was presented in text and participants spent the entire time imagining (or recalling) their most creative (or appropriate) response (12 s). Lastly, each participant verbalized their response into an MRI-compatible microphone (5s; cf., Benedek, Jauk, Fink et al., 2014; Beaty et al., 2018) while a research assistant also recorded each response so that idea quality could be assessed afterwards by four trained raters. Raters were blind to participants' identities (responses were alphabetized and deidentified) and they provided ratings for each idea on a scale of 1 (*not at all creative*) to 5 (*very creative*) using the criteria of uncommonness, remoteness, and cleverness of responses (Silvia et al., 2008; see Table 3 for inter-rater correlations). A practice phase preceded fMRI measurement in order to familiarize participants with the trial sequence.

Behavioral task procedures. In addition to the fMRI divergent thinking assessment, participants completed two AUTs lasting 3 minutes each. This AUT measurement allowed us to compare divergent thinking performance between an fMRI assessment requiring brief AUT ideation and a conventional AUT protocol with a longer assessment period. Participants were given the same "be creative" instructions (Beaty, Silvia et al., 2014; Nusbaum et al., 2014) and were asked to continuously generate ideas for the stimulus items *box* and *rope*, which had not been presented during the fMRI assessment. Responses were typed by participants into a text field using MediaLab software and recorded so that the idea quality of individual responses could be subsequently assessed by the same four blinded raters (along with the fMRI scanner responses).

Attentional Control and Intelligence Assessments

Executive attention tasks. Participants completed three measures of attentional restraint (Kane et al., 2016; McVay & Kane, 2012).

The *Antisaccade Letters* task required visual identification of a target letter on a computer screen. Participants completed 18 response-mapping practice trials and 12 antisaccade practice trials (see Kane et al., 2001). Ninety antisaccade experimental trials were presented to participants, during which three centrally-located fixation asterisks appeared on the screen for either 200 (18 trials), 600 (18 trials), 1000 (18 trials), 1400 (18 trials), or 1800ms (18 trials) in random order. Subsequent flashing cues ("=") preceded target letter presentation 8.6 c to the left or right of fixation. Letter targets (B, P, or R) were located opposite of the flashing cue. Letter targets corresponded with a response keypad labeled B (30 trials), P (30 trials), and R (30 trials). Pattern-masking of the target letter occurred after 100ms. The dependent variable for this task was the proportion of correct keypad responses.

The *Numerical Stroop (N-Stroop)* task required participants to identify the number of digits presented on computer screen during each trial, while ignoring the identity of the digits. One horizontal row of 2-4 repeating digits (in Courier New 24 pt. font) was presented in the center of the screen for each trial. Numerical targets corresponded with one of three labeled keys on a response keypad (2, 3, 4), which allowed participants to report the number of digits. Participants completed two seamless blocks of 150 trials

(300 total). Each block was 80% congruent (120 trials in each block) for both number of digits and digit identity (e.g., *333*). Incongruent trials presented conflicting numbers and identities (e.g., *222*). The dependent variable for this task was mean reaction time (RT) on incongruent trials on the first block; although attention control is ideally measured as a difference score between incongruent and congruent RTs, this difference score did not correlate with the other executive variables (*r*s = -.10–.10) and so, like many prior studies, we used RTs on incongruent trials instead as our indicator of attention control (e.g., McVay & Kane 2012b; Kane et al., 2016). There were two unanalyzed thought probes in block one and 20 analyzed thought probes in block two, which was specifically implemented to measure mind wandering (thought probes followed 13% of trials in block 2; see "*Mind wandering assessments*").

The *Semantic Sustained Attention to Response (SEM-SART)* task required participants to respond via spacebar press to target words presented on a computer screen that were members of a prespecified semantic category (e.g., animals), while inhibiting responses to a different category (e.g., vegetables). All target stimuli were presented for 300 ms followed by a 1500 ms mask (XXXXXXXX). First, participants completed 10 practice trials responding to boys', but not to girls' names. Next, 5 blocks of 135 trials were presented (675 total trials) and were further partitioned into 3 seamless "mini-blocks" of 45 trials. There were 40 "go" trials (i.e., requiring a response) and 5 "no-go" trials (i.e., requiring response inhibition). In each mini-block, there were 3 thought probes following no-go trials (45 total probes; see "Mind wandering assessments"). There were two dependent variables for this task: the SD of RTs to "go" trials and d′, which corresponds with the normalized proportion of correct categorization responses minus the proportion of commission errors/failed inhibitory responses.

Mind wandering assessments. During the N-Stroop and SEM-SART, participants reported their immediately preceding thoughts by responding to several unpredictable thought probes (see McVay & Kane, 2009, 2012a, 2012b; probe placements in each task are detailed above). Prior to N-Stroop and SEM-SART task completion, participants engaged in 90 thought probe practice trials during which they judged whether colored X's presented for 3000 ms each were warm hues (red, yellow, pink) or cool hues (blue, dark blue, purple) via keypad press. Probes followed 12 (13.3%) practice trials. Each probe specifically

asked: “What are you thinking about?” after which participants were instructed to press a corresponding number on the keypad that most represented the content of their thoughts. Participants were asked to report on their thoughts immediately preceding unpredictable thought probes during the N-Stroop and SEM-SART tasks. A set of eight thought content items was presented on the computer screen and re-explained for each probed task. The thought content items (italicized as follows) were used to calculate TUTs (see Kane et al., 2016; McVay & Kane, 2009, 2012a, 2012b). (1) *The task*, thoughts pertaining to the executive attention task (e.g., task stimuli or appropriate responses); (2) *Task performance*, thoughts focused on evaluating one’s immediate task performance; (3) *Everyday things*, thoughts about recent or forthcoming events salient to one’s daily life; (4) *Current state of being*, thoughts about one’s physical or emotional state (e.g., hunger, sleepiness); (5) *Personal worries*, thoughts about fears, and/or troubling influences on one’s life; (6) *Daydreams*, thoughts that are fantastical and disconnected from reality; (7) *External environment*, task-unrelated thoughts about the immediate environmental context; (8) *Other*, only thoughts which failed to align with the 7 alternative categories. The proportion of TUTs was defined at response options 3-8. The Appendix presents descriptive statistics for each mind-wandering response category as a proportion of all TUT reports. Probe practice performance was not analyzed; the TUT dependent variables for the N-Stroop and SEM-SART attention control tasks are described below.

N-Stroop-TUT. The total proportion of reported TUTs following thought probes (e.g., 10 reports of mind wandering following 20 total probes in block 2 = 0.5).

SEM-SART-TUT. The total proportion of reported TUTs following thought probes (e.g., 20 reports of mind-wandering following 45 total probes = 0.44).

Gf. Participants completed three measures of *Gf*. The *number series task* (Thurstone, 1938) required participants to correctly identify a numerical pattern by selecting the next number in a sequence (15 trials, 5 minutes). The dependent variable for this task was the sum of correctly reported numbers across trials. The *letter sets task* (Ekstrom et al., 1976) required participants to identify a letter pattern by selecting a set of four letters that violated a task-rule across a larger set (16 trials, 4 minutes). The dependent variable for this task was the sum of correctly identified rule violations. The *series completion task* from the Culture

Fair Intelligence Test (CFIT; Cattell & Cattell 1961/2008) required participants to select a fourth image that most appropriately completed the visual pattern represented by three sequential images (13 trials, 3 minutes). The dependent variable for this task was the sum of correct images selected.

Analysis Plan and Model Specification

Outliers for executive attention task performance were identified using boxplots. Specifically, observations that exceeded three times the interquartile range (IQR) from the upper and lower plot hinges (Q1 - 3 * IQR or Q3 + 3 * IQR) were excluded from subsequent analyses. In total, 168 participants were retained for the antisaccade task, 164 for N-Stroop, 165 for SEM-SART (rtsd), 169 for SEM-SART (d')), and 166 for both mind wandering measurements (N-Stroop-TUT and SEM-SART-TUT). Latent variable models were specified and estimated using maximum likelihood estimation in Mplus 8. Using the behavioral tasks as indicators, we specified the latent variables attention control (antisaccade, N-Stroop, and SEM-SART (rtsd) and SEM-SART (d')), mind wandering rate (N-Stroop-TUT and SEM-SART-TUT), and *Gf* (number series, letter sets, and series completion). The factor variances were fixed to 1, and the loadings for the two mind wandering indicators were constrained to be equal. Using idea quality assessed by the four independent raters (Rs) as indicators, we specified three lower-order latent divergent thinking variables: d_box (R1, R2, R3, and R4), dt_rope (R1, R2, R3, and R4), and dt_MRI (R1, R2, R3, and R4). These lower-order factors were in turn specified as indicators of a higher-order DT factor (cf., Frith et al., 2020). The measurement models informed a series of regression and bifactor models that assessed specific and general contributions of attention control, *Gf*, and mind wandering on DT. Attention control measures (e.g., reaction time) were standardized prior to analysis; the standardized effects reported below correspond with the *r* metric, which can be interpreted using the established small (.10), medium (.20), and large (.30) guidelines (Gignac & Szodorai, 2016). Additionally, measurement model fit can be interpreted using the established acceptable (CFI = .90, TLI = .90, RMSEA = .08, SRMR = .08) and excellent (CFI = .95, TLI = .95, RMSEA = .05, SRMR = .05) fit indices (Kline, 2015).

Results

Descriptive statistics for attention control, mind wandering, and *Gf* measures are displayed in Table 1. Descriptive statistics for the divergent thinking measures are displayed in Table 2. Correlations among all observed variables are displayed in Table 3.

Confirmatory Factor Analyses

We first specified a measurement model for DT (n = 186), which fit well: χ^2 (51 df) 78.354, p = .008; CFI = .985; TLI = .98; RMSEA = .054 [90% CI: 0.028, .076]; SRMR = .04. This model reproduces our prior work with the same behavioral data (Frith et al., 2020) showing significant loadings of the two lab-based DT tasks (box and rope) and the MRI-based task onto a higher-order DT factor (see Frith et al., 2020, for the lower-order DT factor solution).

Next, we specified a measurement model to assess how the four attention control variables (antisaccade, N-Stroop, SEM-SART [rtsd], and SEM-SART [d']) load onto a latent attentional control factor (AC; n = 169). The residual correlation of rtsd and d' was modeled because these variables came from the same task (i.e., SEM-SART). This model fit the data well: χ^2 (1 df) 1.745, p = .187; CFI = .990; TLI = .942; RMSEA = .066 [90% CI: 0, .228]; SRMR = .022; all indicators loaded significantly onto the latent *AC* variable, with antisaccade accuracy showing the highest loading.

Our final measurement model examined loadings of the three Gf tasks onto a latent Gf factor (n = 184). This model showed good fit: χ^2 (1 df) 1.275, p = .259; CFI = .995; TLI = .986; RMSEA = .039 [90% CI: 0, .204]; SRMR = .07.

We next specified a confirmatory factor analysis to model relationships between AC, DT, *Gf*, and mind wandering (MW; n = 186). The model fit the data well: χ^2 (181 df) 243.739, p = .001; CFI = .97; TLI = .965; RMSEA = .043 [90% CI: .028, .057]; SRMR = .054. We found significant positive correlations between *Gf*, AC, and DT factors (p < .001; see Figure 1), with large magnitudes (95% CI in brackets): *Gf* and DT, r = .38 [19, .57]*;* AC and DT, r = .41 [.22, .60]; AC and *Gf*, r = .60 [.41, .79]. Consistent with prior studies, the model also showed a significant, medium negative correlation between AC and MW, r = -.24 (e.g., Kane et al., 2016; Robison & Unsworth, 2018; Unsworth & Robison, 2017) with all other MW intercorrelations small and non-significant. Results thus replicate the established correlation between *Gf*

and AC (Engle, 2018; Shipstead et al., 2014; Unsworth & Spillers, 2010) and Gf and DT (Batey et al., 2010; Beaty, Silvia et al., 2014; Benedek et al., 2012; Benedek, Jauk, Sommer et al., 2014; Furnham et al., 2005, 2008; Nusbaum & Silvia, 2011; Silvia, 2008; Silvia & Beaty, 2012; Silvia, 2015; Sligh et al., 2005), with a novel finding being a large correlation between AC and DT.

Multiple Regression of AC, DT, Gf, and MW

Having modeled latent correlations, we then specified a structural regression model to assess the relative contribution of AC, *Gf*, and MW to DT. This allowed us to test a key question of interest: does attention control predict divergent thinking, above and beyond *Gf*? To address this question, we modeled AC, *Gf*, and MW as predictors of DT (note the fit indices were identical to the CFA). Interestingly, despite large correlations found for the CFA, this regression model showed nonsignificant effects of *Gf* on DT (β = .22, p = .15), AC on DT (β = .26, p = .09), and MW on DT (β = -.05, p = .62), indicating that AC and *Gf* do not *uniquely* predict DT; their predictive power apparently is driven by the shared variance among two or more of these constructs.

Bifactor Analysis of Common Executive Attention

The fact that the shared AC-*Gf* variance appeared to play a role in the prediction of DT motivated a bifactor model to estimate the effects of both a general executive control factor (i.e., the variance common to AC, *Gf*, and MW indicators) and residual *Gf*-specific and MW-specific factors on DT. Modeling general and specific factors in the same bifactor model allows for a parsimonious interpretation of variance across tasks not captured by a general factor. However, specific factors may also be incorporated into the general factor when indicators cannot be statistically distinguished from it. That is, an indicator may not demonstrate residual variance distinct from a general factor.

We first specified a bifactor CFA, with a general "executive attention" factor and specific *Gf* and MW factors (n = 185). The executive attention and residual factors (*Gf* and MW) were modeled to be orthogonal. This model converged and adequately fit the data: χ^2 (23 df) 42.388, p = .008; CFI .92; TLI = .875; RMSEA = .068 [90% CI: .034, .099]; SRMR = .06. All indicators loaded significantly onto the general executive factor, with the exception of N-Stroop TUTs (β = -.14, p = .14) and Cattell Series Completion

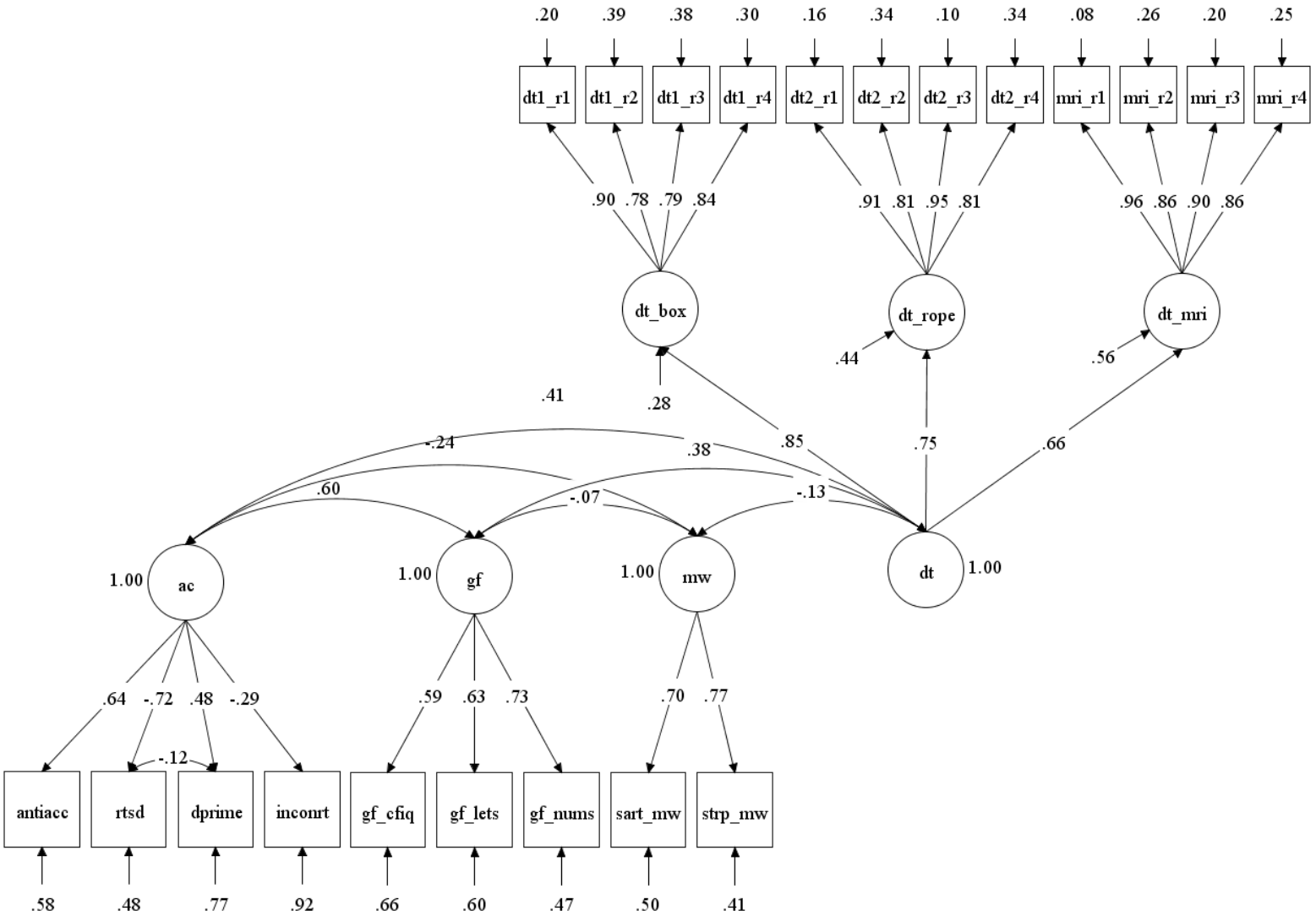

Figure 1. Confirmatory factor analysis of attention control, divergent thinking, fluid intelligence, and mind wandering relationships. ac = attention control; antiacc = antisaccade; rtsd = SEM-SART (SD of RTs to "go" trials); dprime = SEM-SART (difference between proportion of correct responses and failures); inconrt = N-Stroop; gf = fluid intelligence; gf_cfiq = Cattell Series Completion; gf_lets = fluid intelligence, letter sets; gf_nums = fluid intelligence, number series; mw = mind wandering; sart_mw = TUTs during SEM-SART; strp_mw = TUTs during N-Stroop; dt = divergent thinking; dt_box = divergent thinking, box (raters 1-4); dt_rope = divergent thinking, rope (raters 1-4); dt_mri = latent variable of creativity ratings from MRI trials (rater 1-4); N = 186.

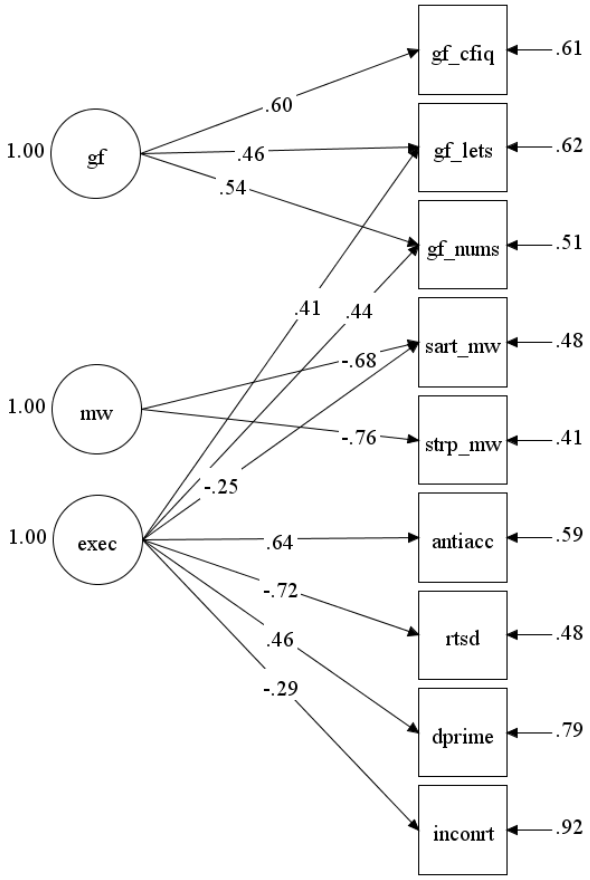

Figure 2. Bifactor confirmatory factor analysis of fluid intelligence, mind wandering, and general executive attention. Only significant paths are shown. gf = fluid intelligence; gf_cfiq = Cattell Series Completion; gf_lets = fluid intelligence, letter sets; gf_nums = fluid intelligence, number series; mw = mind wandering; sart_mw = TUTs during SEM-SART; strp_mw = TUTs during N-Stroop; exec = general executive attention; antiacc = antisaccade; rtsd = SEM-SART (SD of RTs to "go" trials); dprime = SEM-SART (difference between proportion of correct responses and failures); inconrt = N-Stroop; N = 185.

(β = .17, p = .07); the highest loading on the executive factor was SART rtsd, followed by antisaccade accuracy (see Figure 2). This bifactor solution is consistent with past work reporting a common executive factor underlying *Gf* and AC (Benedek, Jauk, Sommer et al., 2014).

How do general executive control and specific *Gf* and MW factors predict DT? A bifactor regression model examined how these common and specific factors relate to DT ability. The model converged and fit the data well: χ^2 (179 df) 238.592, p < .001; CFI = .971; TLI = .966; RMSEA = .042 [90% CI: .027, .056]; SRMR = .049 (see Figure 3). The general executive factor significantly predicted DT (β = .40, p < .001); however, the model yielded nonsignificant effects of residual *Gf* (β = .20, p = .09) and MW (β = -.05, p = .67), indicating that the relationship between *Gf* and DT is driven by shared variance with a common executive attention factor.

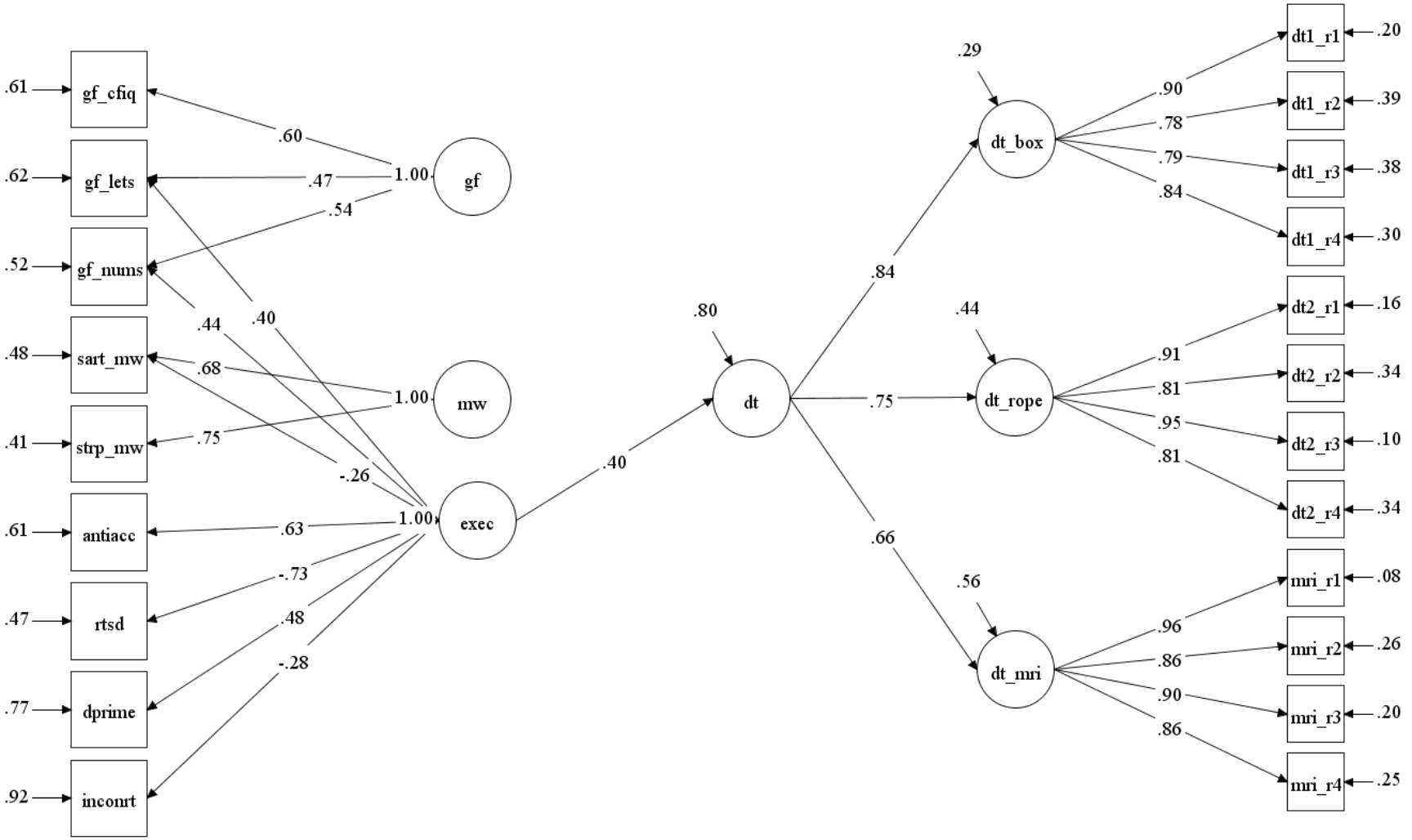

Figure 3. Bifactor multiple regression analysis of the contribution of fluid intelligence, mind wandering, and general executive attention to divergent thinking. Only significant paths are shown. gf = fluid intelligence; gf_cfiq = Cattell Series Completion; gf_lets = fluid intelligence, letter sets; gf_nums = fluid intelligence, number series; mw = mind wandering; sart_mw = TUTs during SEM-SART; strp_mw = TUTs during N-Stroop; exec = general executive attention; antiacc = antisaccade; rtsd = SEM-SART (SD of RTs to "go" trials); dprime = SEM-SART (difference between proportion of correct responses and failures); inconrt = N-Stroop; dt = divergent thinking; dt_box = divergent thinking, box (raters 1-4); dt_rope = divergent thinking, rope (raters 1-4); dt_mri = latent variable of creativity ratings from MRI trials (raters 1-4); N = 186.

Discussion

The present study explored the unique and shared contributions of executive attention and *Gf* to divergent thinking performance. We predicted that executive attention control would predict divergent thinking and would help to explain the contribution of *Gf* to creative cognition. In line with earlier work, we observed distinct positive associations between executive factors and divergent thinking, as well as *Gf* and divergent thinking (Benedek, Jauk, Sommer et al., 2014). However, findings from this study build upon previous research by demonstrating additional support for the executive nature of creative cognition, which appears to be predominantly driven by executive attention. That is, general executive attention control emerged as a higher-order factor that attenuated the strong (and often-observed) relationship between *Gf* and divergent thinking. We also found that mind wandering, as measured using TUTs, was a negative, nonsignificant predictor of divergent thinking performance—consistent with some past work (Smeekens & Kane, 2016; but see Baird et al., 2012)—suggesting that a tendency to engage in task-unrelated thought during executively-demanding tasks is not conducive to generating original ideas. Taken together, this study is the first to provide evidence suggesting that the relationship between *Gf* and DT is driven by the top-down control of attention.

We used a latent variable approach to examine the unique effects of *Gf*, attention control, and mind wandering on divergent thinking, with attention control yielding the largest individual effect on divergent thinking performance. Initially, we observed a medium correlation of *Gf* with divergent thinking, which is similar to evidence highlighting the role of fluid reasoning ability in creative cognition (Akhtar & Kartika, 2019; Batey et al., 2010; Beaty, Nusbaum, & Silvia, 2014; Beaty, Silvia et al., 2014; Benedek et al., 2012; Benedek, Jauk, Sommer et al., 2014; Cho et al., 2010; Furnham et al., 2005, 2008; Karwowski et al., 2016; Kenett, et al., 2016; Liu et al., 2019; Nusbaum & Silvia, 2011; Preckel et al., 2006; Silvia, 2008; Silvia & Beaty, 2012; Silvia, 2015; Sligh et al., 2005). Additionally, in the present research, the Gf path to divergent thinking became non-significant in a structural regression model that included attention control as a predictor, and in a structural bifactor model with a general attention control factor and a residual Gf-specific factor. Benedek, Jauk, Sommer and colleagues' (2014) found a weakened, albeit significant, residual

correlation between *Gf* and divergent thinking when the executive functions updating, shifting, and inhibition were modeled as latent predictors. However, updating ability, which is thought to be governed by broader attention control (Engle et al., 2002; Kane et al., 2001), largely accounted for the attenuated relationship between *Gf* and divergent thinking (Benedek, Jauk, Sommer et al., 2014). Our findings uniquely extend this line of evidence and provide preliminary support for attention control as a core mechanism underlying the intelligence-creativity relationship.

There are several reasons why attention may be central to creative cognition. First, focused attention has been suggested to benefit divergent thinking (Zabelina et al., 2018). This is because top-down executive control processes are thought to permit focused, goal-directed internal attention (Benedek et al., 2011; Benedek, Jauk, Sommer et al., 2014) that guides memory search and facilitates the efficient generation of remote, novel ideas at the expense of dominant, but conventional ideas (De Dreu et al., 2012; Gilhooly et al., 2007; Nusbaum & Silvia, 2011; Wiley & Jarosz, 2012; Zabelina et al., 2016). Additionally, working memory capacity appears to be associated with the maintenance of attention and persistence during divergent thinking (Baas et al., 2008; De Dreu et al., 2012). This ability to selectively and effortfully focus attention on task-relevant stimuli aligns with the *controlled-attention* theory of creativity (Beaty, Silvia et al. 2014; Benedek et al., 2012; Jauk et al., 2013).

However, creative cognition has also been favorably associated with both "leaky" and flexible attention (Baird et al., 2012; Zabelina & Beeman, 2013; Zabelina et al., 2015; Zabelina & Robinson, 2010). Leaky attention is characterized by a natural tendency to diffusely attend to a panoply of extraneous stimuli, which is thought to allow potentially novel connections to be more readily identified (Carson et al., 2003; Zabelina, 2018). The benefits of leaky attention may be explained via the *associative theory* of creativity (Mednick, 1962; Zabelina et al., 2016). This is because remotely linked semantic concepts may extemporaneously pass through the attentional filter, promoting the accessibility of novel ideas with minimal top-down executive control (Eysenck, 1993, 1995; Martindale 1981, 1995). Leaky attention is also more consistently linked to real-world creativity, suggesting that creative achievement may benefit from a more diffuse attentional scope, and thus a less selective filter that permits the entry of "irrelevant" stimuli

into conscious awareness (Zabelina et al., 2016). On the other hand, flexible attention may constitute a controlled ability to switch from diffuse to directed attentional states (Gabora, 2010; Vartania, 2009; Zabelina & Robinson, 2010). In this way, flexible attention may be analogous to an executive strategy for initiating a broad search of semantic knowledge and then focusing internal attention to selectively retrieve information that supports divergent thinking (Beaty & Silvia, 2012; Benedek et al., 2012; Fink et al., 2009; Silvia et al., 2014; Zabelina, 2018). Previous work suggests that higher divergent thinking performance is associated with the ability to rapidly shift attention to relevant aspects of the task, while inhibiting incoming distractors capable of inundating attention (Cassotti et al., 2016; Zabelina et al., 2016). Although the proposed benefits of attention control to creativity may be attributed to associative cognition and controlled-attention, it is important to emphasize that the roles of *Gf* and executive attention likely depend on the creativity outcome measured. That is, creativity assessed via divergent thinking may be more influenced by *flexible* attention compared to creativity assessed via creative behavior/achievement, which appears to benefit from *leaky* attention (Zabelina et al., 2016). It is therefore important for continued empirical efforts to study whether *Gf* and executive attention also contribute to real-world creativity, and to what extent.

The integration of both *associative* and *controlled-attention* theoretical perspectives can offer a clarified interpretation of the role of attention for creative thinking across domains. Specifically, several lines of evidence have identified a flexible semantic network structure that tends to characterize creative thinkers (Benedek et al., 2017; Gray et al., 2019; Kenett et al., 2014, 2018; Kenett & Faust, 2019). The scope of attention within this structure may be broadly distributed across a range of associative links (Gruszka & Necka, 2002; Rossman & Fink, 2010), although this does not necessarily mean that the mental search for novel response candidates is operating in a spontaneous, uncontrolled manner. Rather, the array of possible associations within this network is likely constrained by executive operations, which minimize the salience of less creative or task-inappropriate mental representations (Nusbaum & Silvia, 2011; Unsworth et al., 2011). Relatedly, Faust and Kenett (2014) developed a model that views semantic processing along a continuum that spans highly organized, rigid structure at one extreme, to a chaotic, uncontrolled structure at the other. Neither extreme appears to optimally benefit creativity because while

creative cognition requires expansive and atypical semantic processing, top-down regulation effectively counters the intrusion of bizarre, irrelevant stimuli (Faust & Kennett, 2014; Kenett et al., 2014).

Taken together, relaxing attention is capable of reinforcing novel idea generation, whereas attentional persistence may also ensure that novel ideas are useful and task-appropriate (Gabora, 2010). Therefore, we contend that these seemingly disparate perspectives need not be viewed as incompatible. People must be able to selectively focus attention, inhibit extraneous information, and flexibly shift attention across multiple elements in the problem-solving process (Vartanian, 2009; Zabelina et al., 2016; Zabelina, 2018). To this point, attention is one fundamental aspect of creative cognition that requires direction to optimally assist ideation and problem-solving (Zabelina, 2018). Without sufficient top-down control of attention, creative problem-solving appears to suffer; however, the duration and strength of control necessary for creative thinking has not been unequivocally pinpointed (Chrysikou, 2019). Although studies have shown that creative individuals exhibit greater attention control than their less-creative counterparts (Baas et al., 2008; De Dreu et al., 2012), work also suggests that control is fleeting (Zabelina et al., 2016; Zabelina, 2018). Transient, yet goal-directed attention regulation may help explain why creative individuals are able to readily shift focus across multiple stimuli to generate a variety of original responses (Zabelina et al., 2015), and it may also signify a protective mechanism against unintentional mind-wandering.

Being distracted against one's will likely indicates that one is not in full control of their thoughts, but *purposefully* relaxing attentional constraints may portend a seemingly paradoxical ability to regulate attention more effectively. Mind wandering, which is often measured as TUTs, exhibits variable associations with creative thinking. As aforementioned, some research suggests that mind wandering, while engaged in an undemanding task, offers modest benefits to creative cognition (Agnoli et al., 2018; Baird et al., 2012; Sio & Ormerod, 2009) perhaps via enhanced associative processing (Agnoli et al., 2018; Baird et al., 2012). However, other evidence points to mind wandering as a manifestation of executive control failures that do not subserve creative thinking (Hao et al., 2015; Smeekens & Kane, 2016). Similarly, we found that mind wandering was not significantly associated with divergent thinking. While we anticipate

that unintentional mind wandering is equivalent to attentional control failure, it may not always derail the divergent thinking process.

It is notable that unproductive lapses in executive task-related attention appeared to bear no relation to divergent thinking performance in this study. However, this finding extends recent evidence showing that mind-wandering is not causally related to the creative quality of ideas (Smeekens & Kane, 2016). Nevertheless, future work should consider alternative methods for assessing mind-wandering. We probed TUTs in (only two) shorter executive function tasks (approximately 20 minutes) and did not compare this variety of mind wandering to mind wandering during the divergent creativity tasks. First, measuring TUTs in longer tasks could reveal significant effects of mind wandering on divergent thinking outcomes, as attention may be harder to control over longer assessment periods (Smeekens & Kane, 2016); however, we chose to employ shorter executive function tasks to offset the potential for undue participant time burden and attrition in this multi-phase study.

Second, research should examine whether individuals who perform well on divergent thinking tasks are not only better able to regulate attention, but also whether an ability to recover more quickly from distracting information is also beneficial to creative cognition. That is, it may not be that those with high executive attention control are impervious to the allure of distraction; perhaps these individuals are simply able to combat interfering stimuli by readily switching attention back to the target task (Zabelina, 2018). One way to investigate this in the laboratory may be to examine the time course of distraction-recovery from the point of attending to task-irrelevant stimuli, to switching attention back to salient aspects of the target task (Fukuda & Vogel, 2011). Another way to explore this dynamic relationship between distraction and attention recovery may be to model the content of TUTs. Although beyond the scope of the present experiment, recent work has shown that individuals with higher executive control exhibit more varied, albeit infrequent, mind wandering episodes (Welhaf et al., 2020). Future research should investigate whether abbreviated streams of TUTs flow in many directions because higher ability individuals are better able to maintain task-relevant goals. It is plausible that fluctuating TUTs may serve as functional cues to re-focus attention on the task at hand, or be shallowly entertained, which may allow for efficient attentional

switches back to task-relevant goals (Welhaf et al., 2020). Additionally, more work is needed to clarify whether certain types of off-task thought would be more (or less) conducive for creative idea generation. Preliminary evidence suggests that in controlled laboratory contexts: 1) participants' TUTs about the external environment may occur infrequently, 2) higher executive control is related to less TUTs pertaining to one's current state, and 3) lower executive control is related to more TUTs featuring personal worries (Welhaf et al., 2020). A natural extension to this line of research is to address not only the type of TUTs and when they occur, but also to determine the impact of specific TUT categories on creative cognition. However, future research in this area should also consider accounting for low endorsement rates of specific TUT categories with larger samples and perhaps Poisson modeling due to skew and kurtosis.

Furthermore, when engaged in unintentional mind wandering, attentional focus spontaneously shifts to internal thoughts, rather than goal-directed consideration of the task at hand (Agnoli et al., 2018; Smeekens & Kane, 2016). Experiments designed to assess intentional and unintentional mind wandering may be useful to isolate differential impacts of mind wandering type on creative thinking. Although, it is important to note that other research suggests that too much deliberate mind wandering may also conflict with task goals and harm divergent thinking performance (Agnoli et al., 2018). Continued research is needed to clarify whether there is an optimal balance between deliberately attending to extraneous thoughts and diminishing their intrusion. This will facilitate a better understanding of the interplay between focused attention and mind wandering in the context of divergent thinking. Lastly, our study evaluated the impact of attention control on domain-general divergent thinking, but the utility of mind wandering for domain-specific creativity (e.g., artistic, scientific, etc.) also warrants examination. It is possible that experience and/or expertise in a given domain may impact the way individuals respond to task-related mental workload, and thereby dictate the extent to which TUTs impact creative cognition.

In conclusion, our findings suggest that attention control supports divergent thinking above the effects of *Gf*, which lends additional credence to the executive nature of creative cognition. Moreover, the putative role of mind wandering in creative thinking warrants additional investigation, as TUTs may represent executive control failures, but could also allow "irrelevant" stimuli to pass through the attentional

filter for productive exploration during divergent thinking. Continued work is needed to further empirical understanding of the influence of attention control on creativity—such as modeling the unique and shared contributions of attention and general intelligence factors in addition to *Gf* (e.g., crystallized intelligence, visuospatial intelligence, and broad retrieval ability)—and also potentially manipulating attention during creativity assessment to examine consequences of mind wandering while generating novel ideas and solutions.

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Table 1

Descriptive statistics for fluid intelligence, attention control, and mind wandering measures

Task	*M*	*SD*	*R* (min-max)	*Skew*	*Kurtosis*
gf_cfiq	7.97	1.63	3-11	-0.58	0.40
gf_letters	8.93	2.21	1-14	-0.30	0.53
gf_nums	9.55	2.69	3-15	-0.05	-0.61
rtsd	166	61	52-399	1.08	1.42
dprime	2.05	0.88	-0.13-5.79	0.66	1.56
antiacc	0.70	0.16	0.3-0.98	-0.46	-0.75
inconrt	680	103	481-1069	1.11	1.71
sart_mw	.47	0.23	0-1	0.12	-0.43
strp_mw	.37	0.21	0-0.92	0.45	-0.43

Note. gf_cfiq = fluid intelligence, Cattell Series Completion; gf_letters = fluid intelligence, letter sets; gf_nums = fluid intelligence, number series; rtsd = SEM-SART (SD of RTs to "go" trials); dprime = SEM-SART (difference between proportion of correct responses and failures); antiacc = antisaccade; inconrt = N-Stroop; sart_mw = TUTs during SEM-SART; strp_mw = TUTs during N-Stroop.

Table 2

Descriptive statistics (creativity ratings), by rater, for the divergent thinking tasks

Task	*M*	*SD*	*R* (min-max)	*Skew*	*Kurtosis*
DT_mri_r1	2.29	0.39	1.22-3.78	0.44	0.79
DT_mri_r2	1.46	0.24	1-2.37	1.04	1.40
DT_mri_r3	1.91	0.29	1-2.70	0.03	-0.16
DT_mri_r4	1.76	0.38	1-3.36	1.08	2.17
DT1_r1	1.90	0.47	1-3.25	0.59	0.23
DT1 _r2	1.45	0.33	1-2.67	0.95	0.55
DT1_r3	1.59	0.37	1-3.33	1.19	3.12
DT1_r4	1.39	0.42	1-3	1.43	2.02
DT2_r1	1.75	0.54	1-3.67	1.10	1.03
DT2_r2	1.50	0.41	1-3.5	1.77	4.82
DT2_r3	1.69	0.44	1-3.5	1.05	1.48
DT2_r4	1.34	0.43	1-4	2.55	9.44

Note. dt1 = divergent thinking, box; dt2 = divergent thinking, rope; dt_mri = divergent thinking, MRI; r1-r4 = rater 1-rater 4.

Table 3

Pearson correlations between all observed variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1. dt_mri_r1	1																				
2. dt_mri_r2	0.83	1																			
3. dt_mri_r3	0.87	0.77	1																		
4. dt_mri_r4	0.84	0.80	0.78	1																	
5. dt1_r1	0.52	0.47	0.40	0.47	1																
6. dt1_r2	0.35	0.26	0.25	0.36	0.68	1															
7. dt1_r3	0.46	0.42	0.38	0.41	0.70	0.58	1														
8. dt1_r4	0.44	0.39	0.35	0.41	0.77	0.70	0.69	1													
9. dt2_r1	0.43	0.32	0.41	0.44	0.50	0.41	0.46	0.48	1												
10. dt2_r2	0.34	0.22	0.33	0.33	0.39	0.36	0.42	0.44	0.77	1											
11. dt2_r3	0.47	0.35	0.43	0.46	0.53	0.47	0.56	0.56	0.86	0.78	1										
12. dt2_r4	0.26	0.21	0.25	0.31	0.38	0.42	0.49	0.52	0.72	0.67	0.74	1									
13. gf_cfiq	0.10	0.13	0.23	0.09	0.13	0.15	0.10	0.08	0.05	-0.01	0.04	0.05	1								
14. gf_lets	0.14	0.18	0.21	0.12	0.12	0.11	0.08	0.12	0.06	0.02	-0.01	0.04	0.27	1							
15. gf_nums	0.17	0.20	0.10	0.17	0.13	0.14	0.18	0.11	0.10	0.11	0.14	0.13	0.31	0.41	1						
16. antiacc	0.10	0.17	0.13	0.08	0.11	0.11	0.25	0.13	0.10	0.09	0.14	0.13	0.19	0.25	0.23	1					
17. rtsd	-0.21	-0.14	-0.20	-0.12	-0.18	-0.16	-0.25	-0.17	-0.13	-0.10	-0.17	-0.12	-0.09	-0.21	-0.25	-0.47	1				
18. dprime	0.12	0.05	0.11	0.12	0.14	0.22	0.11	0.18	0.21	0.15	0.21	0.22	0.11	0.20	0.30	0.25	-0.41	1			
19. inconrt	-0.16	-0.16	-0.15	-0.14	-0.18	-0.10	-0.16	-0.19	-0.03	-0.04	-0.06	-0.07	-0.03	-0.17	-0.13	-0.25	0.27	0.02	1		
20. sart_mw	-0.09	-0.11	-0.10	-0.07	-0.08	0.00	-0.06	0.00	-0.12	-0.14	-0.02	-0.08	0.24	-0.15	0.01	-0.11	0.26	-0.16	0.03	1	
21. strp_mw	0.01	-0.01	0.01	-0.02	-0.12	-0.13	-0.14	-0.11	0.02	0.00	0.03	-0.05	0.06	-0.10	-0.11	-0.02	0.14	-0.10	0.17	0.54	1

Note. dt_mri = divergent thinking, MRI; r1 = rater 1; r2 = rater 2; r3 = rater 3; r4 = rater 4; dt1 = divergent thinking, box; dt2 = divergent thinking, rope; gf_cfiq = fluid intelligence, Cattell Series Completion; gf_lets = fluid intelligence, letter sets; gf_nums = fluid intelligence, number series; antiacc = antisaccade; rtsd = SEM-SART (SD of RTs to "go" trials); dprime = SEM-SART (difference between proportion of correct responses and failures); inconrt = N-Stroop; sart_mw = TUTs during SEM-SART; strp_mw = TUTs during N-Stroop.

Appendix

Descriptive statistics (proportion of TUT reports) for each mind wandering response category

	M		*SD*		*R* (min-max)		*Skew*		*Kurtosis*	
Response Category	SART	Stroop	SART	Stroop	SART	Stroop	SART	Stroop	SART	Stroop
3	0.16	0.16	0.18	0.22	0-0.88	0-1	1.56	1.87	2.43	3.55
4	0.29	0.27	0.24	0.25	0-1	0-1	1.17	0.92	1.2	0.53
5	0.15	0.18	0.18	0.23	0-1	0-1	2.18	1.92	6.16	3.88
6	0.22	0.18	0.21	0.22	0-1	0-1	1.27	1.31	1.71	1.4
7	0.11	0.16	0.15	0.23	0-1	0-1	2.7	1.9	9.77	3.65
8	0.08	0.06	0.13	0.16	0-0.67	0-1	2.17	3.77	4.68	17.1

Note. Response option categories for task unrelated thoughts are defined as 3 = everyday things; 4 = current state; 5 = personal worries; 6 = daydreams; 7 = external; 8 = other (not shown are response options 1 = on-task and 2 = task performance). Average proportions displayed are collapsed across participants.