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Both attentional control and the ability to make remote associations aid spontaneous analogical transfer

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Abstract

Given the widespread belief that analogical processing is an important mechanism for creative problem solving, despite the rarity of spontaneous transfer in laboratory studies, a critical direction for future research is to address which abilities may allow for the spontaneous analogizing between distant (superficially dissimilar) sources and targets. This study explores the role of individual differences in attentional control and the ability to make remote associations and their possible combined effects on spontaneous analogical transfer. Participants attempted to solve Duncker's radiation problem after having been exposed to a distant source as part of an earlier task. Results indicated that both measures of attentional control and the ability to make remote associations uniquely predicted spontaneous transfer between a superficially dissimilar source and target. Further, a critical role was seen for the quality of the representation of the source analog on the likelihood of transfer. The present results affirm that the likelihood of spontaneous transfer depends critically on the quality of the representation for the source, but also suggest that individual differences in the ability to make remote associations may be more conducive to constructing a broader representation of that source than individual differences in attentional control.

Keywords Analogy · Problem solving · Attention · Working memory · Creativity

Every problem that an individual faces on a daily basis is in some way unique. Perhaps the individual has never solved that particular type of problem before or has never encountered it in that specific context. Fortunately, one can bring previous experiences to bear on new problems via analogy. Analogical transfer is a ubiquitous solution process that consists of recalling a relevant prior experience, making appropriate connections between it and the current problem, and drawing inferences to solve the problem (Chan, Paletz, & Schunn, 2012). Unfortunately, many studies have demonstrated that people typically fail to make spontaneous use of prior experience if that experience differs from the current problem in terms of superficial details (Barnett & Ceci, 2002; Gick & Holyoak, 1980, 1983; Reeves & Weisberg, 1994; Ross, 1989).

The classic paradigm that has been used to examine analogical transfer is based on a problem originally researched by Duncker (1945). The Radiation Problem is a problem in which a doctor is tasked with removing a tumor in a patient's stomach. A sufficiently strong dose of radiation is needed to destroy the tumor, but a ray of that strength would also damage surrounding healthy tissue. In order to remove the tumor without damaging surrounding tissue or conducting a surgical procedure, participants need to generate what is referred to as the "convergence solution," (following Gick & Holyoak, 1983) in which the doctor uses multiple weaker rays that simultaneously converge on the tumor to destroy it while sparing healthy tissue. In the paradigm used by Gick and Holyoak (1980, 1983), participants are presented with one or several source stories under the guise of a reading task. These stories generally describe problem-solving situations, some or all of which share structural similarities with the Radiation problem and include a description of a convergence solution. Participants are then presented with the Radiation Problem. When participants who had previously read the analogous source stories demonstrate above-baseline use of the convergence solution, it is considered evidence of analogical transfer.

Most laboratory studies examining analogical transfer with this paradigm find that people frequently fail to spontaneously use relevant, previously-presented information. Instead, prior information is only applied when people are explicitly told to

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consider it (Barnett & Ceci, 2002; Gick & Holyoak, 1980, 1983; Reeves & Weisberg, 1994; see review by George & Wiley, 2018). While ideally participants would recognize a relevant analogical case based on structural overlap between a source and a target (Gentner, 1983), instances of spontaneous analogical retrieval seem to be most commonly driven by superficial overlap between the source and the target and only to a lesser degree by structural overlap. The dominance of superficial similarity in retrieval contributes to a tendency for most analogies to be relatively local, or drawn between very near sources and targets (e.g., Dunbar, 2001). This tendency is generally beneficial, as experiences that share many superficial characteristics often share many structural characteristics as well (Blessing & Ross, 1996). However, this tendency can also limit an individual's ability to transfer information from relevant, but superficially dissimilar, prior experiences. It is this latter type of transfer that is considered to be an important mechanism for reaching creative solutions to difficult problems (e.g., Langley & Jones, 1988). Indeed, Blanchette and Dunbar (2000) have found that when people are asked to generate their own analogies while engaged in a problem-solving task, they tend to generate structurally-similar and superficially-dissimilar analogs. However, when asked to recognize or recall a *particular* relevant analogical case, people demonstrate the tendency towards superficial information identified in other research. This disconnect has been dubbed the "analogical paradox" (Dunbar, 2001).

Given the widespread belief that analogical processing is an important mechanism for creative problem solving, but the low observed likelihood of spontaneous transfer in the classic transfer paradigm, a critical direction for research is to address what factors may allow for spontaneous analogizing between distant (superficially dissimilar) sources and targets. The current study explores the role of individual differences in attentional control and the ability to make remote associations and their possible combined effects on spontaneous analogical transfer. In this way, this study attempts to increase the understanding of what conditions encourage the successful transfer of solutions between superficially dissimilar sources and targets.

Individual differences and analogical transfer

In order to understand how individual differences may influence spontaneous analogical transfer, it is helpful to consider one common theoretical approach conceptualizing the transfer process as a combination of several stages (e.g.m Gick & Holyoak, 1980; Holyoak & Koh, 1987; Reeves and Weisberg, 1994; Ross, 1989). As depicted in Fig. 1, success in the analogical transfer paradigm requires participants to construct a representation of the information present in the source analog, to notice the relevance of the source analog during problem solving and retrieve that source information from memory, and then to map the relationships between the source and the target problem in order to generate inferences that can aid problem solving. Each of these stages may present their own obstacles to success, and performance within each stage may relate to different individual differences.

Attentional control and mapping Prior research on attentional control has mostly investigated its importance on analogical mapping (Morrison, Doumas, & Richland, 2011; Morrison et al., 2004; Richland et al., 2006, 2010; Viskontas, Morrison, Holyoak, Hummel, & Knowlton, 2004; Waltz, Lau, Grewal, & Holyoak, 2000). "Attentional control" refers to the ability to maintain relevant information in the focus of attention while inhibiting irrelevant information. "Mapping" refers to the one-to-one alignment of important elements (i.e., objects or relations) in the source to those in the target. The difficulty of this alignment process is greater when the sources and targets contain multiple relations that must be matched with one another. Moreover, failing to identify the appropriate correspondences may result in incorrect associations being made and inappropriate inferences being generated.

Given the potential complexity of the mapping and adaptation process, this stage is considered to place significant demands on the ability to control attention (Morrison, Doumas, & Richland, 2011; Morrison et al., 2004) in multiple ways. First, the ability to maintain relevant information in working memory is necessary for aligning *multiple* objects and relationships across source and targets. An individual's working memory capacity (i.e., the amount of information that can be maintained in memory while concurrently processing that or other information) has been shown to reflect a domain-general limitation in ability to control attention (Engle, 2002), especially when that capacity is calculated as a composite of performance across multiple span tasks to reduce the influence of task-specific variability. Second, the ability to inhibit irrelevant information may prevent inappropriate alignments, such as those based on superficial, instead of relational, overlap. This inhibition is especially important when that irrelevant or inappropriate information grabs attention immediately and needs to be resisted, as in the antisaccade task, which requires individuals to resist the urge to look toward a visual cue that flashes briefly on one side of a computer display and instead look for a target on the opposite side.

To support this idea, several studies have identified deficits in mapping pictorial analogies among children (Richland et al., 2006, 2010) and older-adults (Viskontas, Morrison, Holyoak, Hummel, & Knowlton, 2004), populations who generally exhibit underdeveloped and declining ability to control their attention, respectively. In these studies, participants are given both the source and target simultaneously and are asked to draw an analogical mapping between the two items. For example, in the people pieces task (Viskontas et al., 2004),

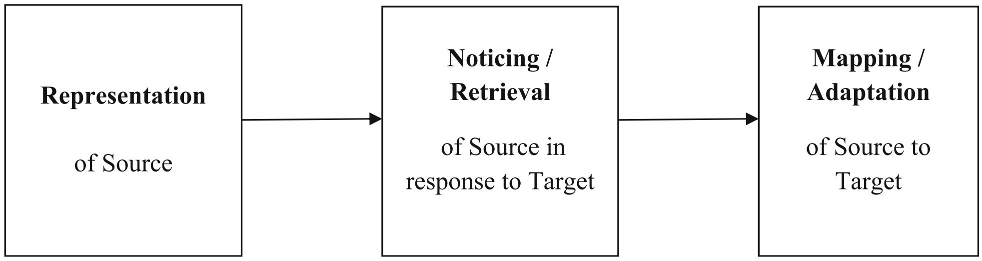

Fig. 1 Sequence of analogical transfer in problem solving

participants are presented first with a pair of cartoon figures that are similar or dissimilar along a series of characteristics (e.g., height, width, or clothing color) and are asked to confirm whether a second pair of individuals demonstrate the same relationships along all or some characteristics as the first pair. Viskontas et al. (2004) demonstrated that older adults have greater difficulty making accurate judgments as a function of relational complexity (the number of characteristics being considered) and the presence of distracting information relative to a college-aged population. They argued that this difficulty is associated with age-related declines in the ability to control attention. Using this same task, Cho et al. (2010) have elaborated on the prefrontal structures associated with cognitive control that activate in response to greater relational complexity and inhibiting distracting information, suggesting these to be dissociable difficulties in analogical mapping, both of which require attentional control to overcome.

In the scene analogy task (Morrison et al., 2004; Richland et al., 2006, 2010), subjects are presented with pairs of images depicting objects in some pattern of relations to one another (e.g., a cat chasing a mouse as a dog watches in one image and a boy chasing a girl as a woman watches in the other image). An object from the first image is identified and participants are asked to indicate the analogous object from the second image. Similar to the results from older adults, young children demonstrate significant difficulties when distractor objects (e.g., a cat present in the second image of the above example) are present in the materials. Morrison et al. (2004) have also demonstrated similar performance problems with a population of frontal lobe-damaged patients that they attributed to deficits in working memory and inhibition. In this same paradigm, Waltz, Lau, Grewal, and Holyoak (2000) have shown that secondary tasks taxing working memory reduce the likelihood that an individual will correctly identify the analogous object in the second image and increase the likelihood that objects will be selected based on simple superficial overlap.

Thus, prior research has provided evidence showing that attentional control facilitates mapping in these simultaneous-presentation paradigms. Specifically, attentional control seems important for dealing with the complexities of mapping including managing increasing relational complexity and ignoring distracting information that may lead to inappropriate associations between items. While this research has been conducted in paradigms in which analogs are presented simultaneously, this work suggests that individual differences in attentional control could also be expected to predict successful mapping in a transfer paradigm in which a source is presented separately from a target.

Attentional control and representation Less work has been done specifically looking at the influence of attention on representation in the context of analogical problem solving. Based on research on text comprehension, one might suspect that better attentional control should improve the ability to represent the source stories. For example, measures of working memory capacity have been found to predict an individual's ability to remember text and to generate inferences and understand the meaning of text (e.g., Daneman & Carpenter, 1980; Friedman & Miyake, 2000; Singer & Ritchot, 1996; Turner & Engle, 1989). As the stories and problems are presented via text, this work suggests that better attentional control may help readers to form better representations of the source information.

Similarly, in prior work on mathematical word problem solving, individual differences in working memory have been found to correlate to solution success (Andersson, 2007; Lee, Ng, & Ng, 2009; Passolunghi, Carnoldi, & De Liberto, 1999), with some suggesting that this relationship may be due to advantages in problem representation (Andersson, 2007; Swanson, Cooney, & Brock, 1993; Thevenot & Oakhill, 2006). Others suggest that those individuals with greater attentional control perform better on word problems due to the ability to inhibit irrelevant information within the problem statement (Passolunghi et al., 1999). If the ability to control one's attention is related to the ability to construct a higher quality representation of a source, then spontaneous noticing of the analogy should be positively related to individual differences in attentional control. Indeed, a recent study by Kubricht, Lu, and Holyoak (2016) has demonstrated that individual differences in fluid intelligence (measured by an abbreviated Ravens' Advanced Progressive Matrices task) predicted spontaneous transfer, and that the positive impact of fluid intelligence on spontaneous transfer was mediated by its influence on source comprehension. Given the substantial relation between measures of attentional control and performance on measures of fluid intelligence (Ackerman, Beier, &

Boyle, 2005; Kane et al., 2004; Wiley & Jarosz, 2012), one might predict that individual differences in attentional control could also have a positive impact on spontaneous transfer, and that this effect may be mediated by how the source case is represented.

However, greater attentional control may not necessarily result in the kind of representations that benefit spontaneous analogical transfer. Research into the relationship between representation quality and analogical transfer has emphasized that the quality of an individual's abstracted representation of the structure of the source (or the *schematic* representation) predicts the likelihood of spontaneously using the source for later problem solving (Gick & Holyoak, 1983). That is, a representation favoring the critical relationships in the source will facilitate transfer. Training intended to promote the inclusion of key structural elements within a source representation, including critical relationships, has been shown to facilitate spontaneous transfer. For example, Gick and Holyoak (1983) had participants read and compare similarities between two analogous source stories both suggesting a "convergence" strategy. The authors argued that comparison across stories facilitated the abstraction of the important structural elements of the convergence solution (the use of many small forces, from many directions, simultaneously). Indeed, reading and comparing stories increased the likelihood of individuals using that strategy to solve a later analogous target problem. Further, those individuals who were considered to have the best schematic representations of the convergence strategy demonstrated the highest rates of transfer. Catrambone and Holyoak (1989) found that greater benefits to transfer could be obtained from simply providing scaffolding questions that guided participants in identifying and encoding the structure of the stories. Other research has shown that self-explanation during the consideration of single sources can confer similar benefits and improve the likelihood of later transfer (Bearman, Ormerod, Ball, & Deptula, 2011).

Ultimately, these studies suggest that those individuals who are best able to represent structural information from the source stories will be most likely engage in spontaneous transfer. However, while one might expect people with greater working memory capacity to have advantages in developing a more complete representation of the source, it is not clear that they will have an advantage in developing this type of transfer-appropriate representation. Thus, it remains an open question how controlled attention might facilitate transfer via source representation.

Remote associations and noticing/retrieval While prior work can be used to suggest that individual differences in attentional control might facilitate both the mapping and representation phases of analogical problem solving, the role that those individual differences may play in successful noticing and retrieval is far less obvious. Retrieval is largely driven by superficial overlap between the source and target, as surface-level details provide the most salient cues to retrieval (e.g., Gentner, Ratterman, & Forbus, 1993; Ross, 1989). However, the cases that come to mind most easily may not actually be helpful for solution, especially when a creative solution is required. Instead, relevant information may be found in more distant, less superficially similar sources.

In these cases, there are multiple possible influences of attentional control. Firstly, it is possible that attentional control may be beneficial, as there is some evidence to suggest that it can predict the ability to break from perseveration. For example, Beaty and Silvia (2012) found that individuals high in fluid intelligence were better able to avoid perseverating on initial and generally obvious responses to a divergent thinking prompt and more likely to quickly generate original ideas. However, there is also evidence to suggest that attentional control may lead to fixation on the initially-retrieved, but unhelpful, solutions (Beilock & de Caro, 2007; Ricks, Turley-Ames, & Wiley, 2007). For example, Beilock and de Caro (2007) found that individuals high in working memory capacity were more likely to perseverate on a previously-learned strategy for solving a problem, even when a simpler strategy became possible to use on later problems. Alternately, individuals low in working memory capacity were more likely to switch to the new strategy.

Another consideration is that people high in attentional control have a greater ability to inhibit information that has been deemed irrelevant. For example, Delaney and Sahakyan (2007) found that people high in working memory capacity were more likely to forget information following an instruction intended to provoke a shift in mental context than were low capacity individuals. Aslan and Bauml (2011) also found that individuals with higher working memory capacity demonstrated more inhibition of irrelevant information in a retrieval-induced forgetting paradigm. Therefore, people with higher attentional control may be more likely to inhibit information that they believe to be irrelevant to later tasks and less likely to be able to make effective use of that information when it becomes relevant.

Instead, research on creativity has suggested that a broader or more diffuse state of attention may facilitate creative thinking (Baird et al., 2012; Carson, Peterson, & Higgins, 2003; Wiley & Jarosz, 2012). Mednick (1962) believed that greater creativity was associated with a less-focused scope of attention that allows an individual to find uncommon connections between concepts. In order to assess this ability, he designed the Remote Associates Task (Mednick, 1962), which requires participants to identify a distant semantic associate common to several presented words. Consistent with the idea that a broader scope of attention may be important for creative thinking, Ansburg and Hill (2003) found that participants' likelihood of using peripheral cues was related to performance on a remote associates task, but not on a deductive reasoning task.

Similarly, Jarosz, Colflesh, and Wiley (2012) found that mild intoxication improves performance on a remote associates task while decreasing performance on a test of working memory capacity. Kim, Hasher, and Zacks (2007) also found that age-related reductions in attentional control led to increased performance on a remote associates task, in this case when solutions were embedded in distractor tasks. Mednick's Remote Associates Task requires participants to identify a distant semantic associate common to several presented words (Mednick, 1962) and is used in the present study to provide a measure of individual differences in the ability to make remote associations. While mapping and representation may benefit from attentional control, the noticing and retrieval of distant analogs may be more likely to benefit from individual differences in the ability to make remote associations. The main hypothesis tested in this study was that spontaneous transfer may rely on both attentional control and this ability.

Overview of the present study

The purpose of this study was to expand on previous research into the relationship between individual differences and analogical transfer. In particular, while previous research has used load-based (e.g., Waltz, Lau, Grewal, & Holyoak, 2000), or non-equivalent group designs (e.g., Richland et al., 2006, 2010; Viskontas et al., 2004), this study used a regression-based approach to explore how individual differences in attentional control and the ability to make remote associations might relate to successful analogical transfer, and to test the hypothesis that both abilities should predict spontaneous solutions in an analogical transfer paradigm. This approach is aligned with other recent work by Kubricht, Lu, and Holyoak (2016), but uses different individual difference measures. The use of multiple measures in this area of research is important to establish convergent validity as to what constructs are relevant.

Consistent with prior research using the Gick and Holyoak (1980, 1983) analogical transfer paradigm, the primary dependent variable of interest was spontaneous generation of the convergence solution, first presented in a source story, while solving the Radiation Problem. Prior research has suggested that the ability to control one's attention should be critical for analogical mapping and could be important for developing representations of source stories in memory. This study also tested whether individual differences in the ability to make remote associations might also predict spontaneous analogical transfer, over and above the contribution of individual differences in attentional control. The main analysis was a hierarchical regression using the measures of attentional control and the ability to make remote associations to predict spontaneous generation of the convergence solution to the Radiation problem following exposure to the Lightbulb story.

To explore the effects of attentional control, this study included both a measure of inhibition (antisaccade) and a composite score of two complex working memory span tasks. By creating a composite measure of working memory performance, this measure better represents the domain-general demands on executive attention common to both tasks as opposed to task-specific characteristics such as mathematical ability (OSpan) or spatial ability (SSpan; Conway et al., 2005; Engle, 2002).

To explore the benefits of the ability to identify remote associations, participants completed a version of the Remote Associates Task (RAT). Like many creative thinking tasks, performance on the RAT relies on multiple modes of thinking (Guilford, 1957; Martindale, 1995). Participants must think divergently to find remote associates, but also convergently to decide on a correct solution. As a result, successful RAT problem solving will depend on both the tendency to consider distant associations as well as the ability to control attention to focus on the correct solution. Given the mix of processes involved in the RAT, the approach taken here was to include measures of attentional control as a first step in a hierarchical regression, and then to enter RAT scores into the second step. Any unique variance contributed by RAT scores in the second step would then reflect the ability to find remote associates that remained after variance explained by attentional control measures had already been included. This allows for the testing of whether there might be a unique role of the ability to find remote associates in predicting spontaneous analogical transfer. While the semantic associations that people need to identify in order to perform well on the RAT are not the same as the structural associations that need to be identified in distant analogy, performance on the RAT task should nevertheless reflect some element of an individual's propensity for making remote associations. This propensity may be an important factor in the noticing and retrieval of distant analogies.

Given that little research has investigated the relationship between individual differences and source representation in analogical transfer paradigms, this was also examined more directly. Following previous work that has also been interested in closely examining the representation phase (Francis, 1999; Gick & Holyoak, 1980), individuals were asked to recall and summarize the source stories after they read them. Those summaries were then coded for the inclusion of multiple concepts present in the story. The number of concepts included (or the "completeness" of the story summaries) was used as a measure of representation quality. A second regression was then conducted to examine whether this representation quality measure was a significant predictor of spontaneous transfer. Additionally, the completeness of the story summaries was included in a mediational analysis to test whether any relationship between individual differences measures and spontaneous transfer might be mediated by the quality of the source representation.

A third regression tested for relations between individual differences and mapping. Ratings of how helpful participants believed the Lightbulb Story to be in generating the convergence solution were collected as an indication of the participant's ability to map the source to the target (i.e., recognize the overlap between the two). Therefore, these ratings provided a measure of the quality of participants' source-to-target mapping. This measure allowed us to test whether controlled attention is particularly important in predicting the ability to map between source and target, as suggested by prior research using other paradigms.

Method

Participants

One hundred and forty-one undergraduates were recruited from the University of Illinois at Chicago subject pool in exchange for course credit. Sixty-six percent were female and the mean age of participants was 19.39 years (*SD* = 1.74). Ten participants were excluded from all analyses due to reporting prior exposure to Duncker's Radiation Problem. Eleven participants were excluded from analysis due to missing or erroneous data on at least one task. The remaining sample available for analyses was 120.

Materials

Analogical transfer task The materials for the transfer task included the Radiation Problem as the target problem and the ultrasound waves/fragile glass version of the Lightbulb Story from Holyoak and Koh (1987) as the source story. The Lightbulb Story presents a situation analogous to the Radiation Problem that describes a solution of using multiple weak forces from multiple directions simultaneously to repair a lightbulb (the convergence solution). This particular version of the source story was selected because pilot testing indicated that approximately half of the participants spontaneously generated the convergence solution to the Radiation Problem after reading this story. This percentage is consistent with prior research using the Lightbulb Story as a source and the Radiation Problem as a target (.52-.55; see George & Wiley, 2018, for review),

In this analogy paradigm, production of the convergence solution is assumed to be the result of transfer because generation of that solution is generally low unless a source story is provided. For example, Duncker (1945) reported only two of 42 subjects spontaneously generated the convergence solution. Similarly, Gick and Holyoak (1980) found that no participants generated the convergence solution in the absence of a source. Finally, our own piloting found that only one participant in 21 proposed the convergence solution when not provided a relevant source.

Antisaccade task The antisaccade task is considered a measure of controlled attention because it provides a measure of participants' abilities to direct their attention towards appropriate stimuli and inhibit attention to inappropriate stimuli (Kane, Bleckley, Conway, & Engle, 2001). This task requires participants to resist a dominant response to look towards a visual cue that flashes on one side of a computer display and instead look towards the opposite side to detect a target stimulus. The task was modeled after Kane et al. (2001) and was presented on computer, with participants completing 54 trials. Each trial started with a ready screen at which participants pressed the spacebar to begin a trial. A fixation cross appeared at the center of the screen and remained for a variable amount of time between 200 and 2,200 ms. After the fixation cross, a "=" flashed in either the right or left side of the screen. A letter was then presented on the opposite side of the screen for 100 ms. This letter was either a "B," "P," or "R." After the letter had been presented for 100 ms, it was masked by the letter "H" for 50 ms and then by the number "8." This last item remained on screen until participants used a button press to indicate which letter had been presented. After providing this response, the next trial began.

Failing to inhibit the dominant response to look at the flashing "=" symbol on one side of the screen makes it difficult for participants to identify which letter was presented on the opposite side. The more that individuals are able to inhibit looking towards the flashing symbol, the more likely they are to accurately identify the presented letter. As such, participant response accuracy serves as a measure of attentional control. Overall accuracy was computed for each participant as the proportion of correctly identified letters out of total trials.

Reliability of this measure was assessed using an odd-even analysis. The reliability between these halves was calculated to be .86 using the Spearman-Brown correction (Spearman, 1910). As average response accuracy was generally high and negatively skewed, the antisaccade accuracy variable was adjusted using an arcsine transformation. Average score on this corrected variable was .99 (*SD* = .27, range: .28 – 1.57).

Complex span tasks Two complex span tasks were completed by participants, Operation Span and Symmetry Span. In contrast to simple sentence span tasks (e.g., Daneman & Carpenter, 1980), performance on *complex* span tasks has been suggested to reflect an individual's ability to control their attention in the face of interference (Conway et al., 2005; Engle, 2002; Kane, Bleckley, Conway, & Engle, 2001). Due to separate processing and storage components, complex span tasks measure the executive attention that is required to maintain relevant information in primary memory while appropriately retrieving information from secondary memory and inhibiting inappropriate retrieval (Unsworth & Engle, 2007).

Operation Span (OSpan) requires participants to remember a list of letters while simultaneously identifying the correctness of arithmetic statements. Symmetry Span (SSpan) requires participants to judge whether an image composed of an 8 × 8 grid of black and white squares was symmetrical or not, and then remember the location of a red square on a 4 × 4 grid. In both tasks, after subjects were presented with between 2 and 5 items, they were prompted to recall all items that they remembered from the set. Three sets of each size were presented (totaling 12 sets per task) in random order so that subjects could not anticipate the size of each set. For each task, scores were obtained by averaging across the proportion of correctly recalled items out of possible items per set.

Reliability was high for these tasks, with Cronbach's alphas of .77 and .83 for OSpan and SSpan, respectively. A composite working memory capacity (WMC) score was obtained by averaging across participants' scores on both tasks. By creating a composite measure of working memory performance, this measure better represents the demand on executive attention common to both tasks as opposed to task-specific characteristics such as mathematical ability (OSpan) or spatial ability (SSpan). Composite measures of working memory capacity have also been shown to be better predictive other higher-order reasoning tasks, such as Ravens Advanced Progressive Matrices (Kane, Hambrick, & Conway, 2005). Average score on this composite working memory variable was .54 (*SD* = .15, Range: .17 - .88).

Remote Associates Task The Remote Associates Task (RAT) provided a measure of individuals' ability to think broadly in order to find distant associations (Mednick, 1962). Participants were presented with 25 compound RAT problems (drawn from Bowden & Jung-Beeman, 2003b). Each problem was comprised of a set of three words with the goal of finding a fourth word that forms a familiar phrase with each of the words in the set. For example, a participant may be presented with EIGHT, SKATE, and STICK. The intended answer is FIGURE, which forms the phrases *figure eight, figure skate,* and *stick figure*. Performance on this task relies on the ability to move beyond strong semantic associates to each word and to activate remote associations in long-term memory. Participants were presented with one problem at a time and given 30 s to generate a solution. Once a solution had been identified, they pressed a button and typed their answer into a text box. RAT scores were computed as the proportion of items that were solved correctly. The average score on this task was .41 (*SD* = .17, range: .00–.84).

Procedure

After providing consent, participants were informed they would be doing a variety of different tasks as part of the study. To begin, participants completed the analogical transfer task. This task was structured after the classic Gick and Holyoak (1980) paradigm for investigating analogical transfer. First, booklets were distributed and participants were given 3 min to read the Lightbulb Story. They were told to pay close attention while reading, as they would be asked to summarize the story. After reading, they were asked to spend 5 min writing a summary of that story. They were allowed to look back at the story while writing their summary. After finishing the summary, the story materials were collected and subjects were told they were moving on to a different "problem-solving" task. The Radiation Problem was then distributed as a second booklet and participants were given 5 min to generate as many solutions to the Radiation Problem as possible.

After completing the Radiation Problem, participants were given a questionnaire that asked them to specifically identify the solution to the Radiation Problem that was suggested by the Lightbulb Story. They were then asked to provide a rating of how helpful they believed the Lightbulb Story to be in generating a solution to the Radiation Problem. Finally, participants were asked whether they had seen or solved the Radiation Problem prior to the study.

Following the problem-solving phase, all participants completed the individual differences tasks in the following order: the Remote Associates Task, the Antisaccade task, Symmetry Span, and Operation Span.

Coding

Source story representation Participants' summaries of the source story, the Lightbulb Story, were coded for the presence of eight concepts:

1. Need for strong force: A high-intensity wave is needed. (SC1)
2. Constraint: A high-intensity wave would break the glass. (SC2)
3. Division of force: She used several ultrasound machines. (SC3)
4. Use of weak forces: She administered low-intensity waves. (SC4)
5. Spatial convergence: She administered waves from several directions. (SC5)
6. Temporal convergence: She administered the waves simultaneously/all at once. (SC6)
7. Combination of forces: The waves combined to achieve desired level. (SC7)
8. Avoid negative: Since low intensity waves were used, the glass was left intact. (SC8)

The proportion of these concepts (out of eight) included in participants' summaries was used as an indication of the quality of their representation of the source story (Summary Completeness). Two independent coders identified instances of each concept in participants' summaries. Inter-rater reliability was .88, with disagreements being resolved by a third rater.

Transfer of convergence solution Solution attempts to the Radiation Problem were evaluated for whether they included the suggestion to use multiple weaker rays simultaneously. The use of this convergence solution was considered spontaneous because it was offered before the explicit prompt to consider the solution from the lightbulb story (e.g., Francis, 1999; Gick & Holyoak, 1980, 1983). Two independent coders identified the presence of convergence solutions in participants' summaries. Inter-rater reliability was .91, with disagreements resolved by a third rater.

Results

Simple correlations between all predictors and outcome variables are reported in Table 1.

The main analysis was a hierarchical regression using the measures of attentional control and the ability to make remote associations to predict spontaneous generation of the convergence solution to the Radiation problem following exposure to the Lightbulb story. Additional analyses explored whether the individual difference measures predicted representation quality (summary completeness) and mapping (story helpfulness). The predictor variables for each of these analyses were antisaccade accuracy and WMC as two different measures of attentional control, and RAT scores as a measure of the ability to make remote associations.

Like many creative thinking tasks, successful performance on the RAT relies on multiple modes of thinking (Guilford, 1957; Martindale, 1995). Participants must think divergently to find remote associates, but also convergently to decide on a correct solution. As a result, successful RAT problem solving performance will depend on both the tendency and ability to consider distant associations as well as the ability to control attention to focus on the correct solution (e.g., Lee & Therriault, 2013; Taft & Rossiter, 1966). Given the mix of processes involved in the RAT, the approach taken here was to include measures of attention control as a first step in hierarchical regressions, and then to enter RAT scores into the second step. The logic behind this approach was that any unique variance contributed by RAT scores in the second step that remained after variance explained by attentional control measures had already been included in a first step, would then reflect the ability to find remote associates. Thus, this approach allows for the use of the RAT to test whether there might be a unique role of the ability to find remote associates in predicting spontaneous transfer. Additional analyses entering these variables in the opposite order were also run to confirm the independent benefits of the two constructs. In all cases, this did not change the results. All predictor variables were z-score transformed prior to being included in the regressions. This allows for clearer interpretation of the odds ratios produced by the logistic regressions.

Table 1 Simple correlations between predictor and outcome variables

Variable	1	2	3	4	5	6
1. Antisaccade	-	.33**	.33**	.07	.34**	.26**
2. WMC		-	.30**	.21*	.36**	.32**
3. RAT			-	.27**	.37**	.28**
4. Summary Completeness				-	.29**	.37**
5. Spontaneous Transfer					-	.49**
6. Story Helpfulness						-

Note. * $p < .05$, ** $p < .01$

Spontaneous convergence solution

Sixty-one participants (50.8%) spontaneously generated the convergence solution to the Radiation Problem. This rate is similar to the spontaneous transfer rate between the Lightbulb Story and the Radiation Problem in prior research (52–55%; George & Wiley, 2018). The first hierarchical logistic regression predicting spontaneous transfer of the solution from the Lightbulb Story is shown in Table 2 with measures of attentional control (antisaccade and WMC) entered in Block 1 before RAT scores in Block 2. Each block of the hierarchical analysis was associated with a significant improvement in model fit as evaluated by chi-square tests. In the full model, and in each block, all three predictor variables were found to be significant predictors of spontaneous generation of the convergence solution. The significant improvement in the model following the addition of RAT scores in Block 2 of the analysis after already entering the attentional control measures in Block 1 supports the idea that there is an additional benefit from the ability to make remote associations in predicting spontaneous generation of the convergence solution.[1]

Individual differences and representation quality

The proportion of the eight concepts from the source story included in summaries ranged from 0 to 1, with participants including, on average, about half of the concepts ($M = 0.48$,

[1] Additional analyses indicated that none of the interaction terms were significant predictors of transfer and their inclusion did not significantly improve model fit (all $ps > .05$).

Table 2 Hierarchical logistic regression predicting spontaneous convergence solution

	B	*SE*	OR	Wald	Chi-square block	Chi-square model	Nagelkerke R-square
Block 1					23.93**	23.93**	.25
Antisaccade	.66	.24	1.94	7.48**			
WMC	.70	.24	2.00	8.75**			
Constant	.05	.20	1.05	.06			
Block 2					7.85**	32.77**	.32
Antisaccade	.56	.25	1.72	5.06*			
WMC	.64	.25	1.89	6.68**			
RAT	.64	.24	1.89	7.14**			
Constant	.07	.21	1.09	.10			

Note: * p < .05, ** p < .01

SD = 0.24). Table 3 presents the results of the regression predicting representation quality as measured by summary completeness. When the measures of attentional control were entered in the first step, the model was a marginally significant predictor of summary completeness, with WMC serving as the only significant predictor. When RAT scores were entered in the second step, it significantly improved the fit of the model such that the model was now significantly predictive of summary completeness. In this full model, only RAT scores were predictive of summary completeness.

Representation quality as a predictor of spontaneous transfer One explanation for this pattern of results is that having a broader rather than narrower attentional focus led some participants to include a broader range of ideas in their summaries. This gave those participants more information to consider when they encountered the Radiation Problem, which then affected their ability to notice the relevance of the source story, retrieve the solution, and apply it.

To test this explanation, a hierarchical logistic regression was conducted predicting spontaneous generation of the convergence solution including all three individual differences variables in the first step and representation quality as measured by summary completeness (completeness) in the second step. For this analysis, summary completeness was z-score transformed, for consistency with other predictor variables. The results of that analysis are presented in Table 4. The addition of representation quality in the second block resulted in a significant improvement in model prediction and representation quality was a significant predictor of spontaneous transfer.

Given that both RAT and summary completeness were significant predictors of spontaneous transfer, and that RAT was a significant predictor of summary completeness, it was possible that the tendency to represent the story more completely might mediate the relationship between RAT performance and spontaneous transfer. To test for this mediation, the PROCESS macro (Hayes, 2013) was used to conduct a regression analysis using bootstrapping (10,000 samples) to evaluate the indirect effect of RAT scores on the generation of the convergence solution, including representation quality (summary completeness) as a mediator and controlling for the influence of the attentional control measures on representation quality and spontaneous solution. That is, this analysis evaluated whether the relationship between performance on the RAT task and spontaneous transfer can be explained by differences in summary completeness (i.e., the *indirect* effect of RAT on spontaneous solution). Bootstrapping is a non-parametric resampling method that estimates a confidence interval for this indirect effect (e.g., Preacher & Hayes, 2004). Unlike the classic Baron and Kenny (1986) approach, it does not assume normality, performs better under low power situations, and directly tests the significance of the indirect path rather than relying on inference from a significant reduction to the magnitude of the direct path. As shown in Fig. 2, this bootstrapping analysis found that the bias-corrected 95% confidence interval on this indirect effect did not cross zero, *B* = .13, *SE* (bootstrapped) = .09, 95% CI = .01–.36. Because zero

Table 3 Hierarchical regression predicting summary completeness

	B	*SE*	B	*T*	R^2	*F*	ΔR^2	ΔF
Block 1					.04	2.69†		
Antisaccade	.00	.02	.002	.02				
WMC	.05	.02	.21	2.18*				
Constant	.48	.02		22.27**				
Block 2					.09	4.01**	.05	6.41*
Antisaccade	-.02	.02	-.06	-.66				
WMC	.04	.02	.16	1.65				
RAT	.06	.02	.24	2.53*				
Constant	3.60	.88		4.09**				

Note: † p < .10, * p < .05, ** p < .01

Table 4 Hierarchical logistic regression predicting spontaneously generating convergence solution including representation quality (completeness)

	B	*SE*	OR	Wald	Chi-square block	Chi-square model	Nagelkerke R-square
Block 1					32.77**	32.77**	.32
Antisaccade	.56	.25	1.76	5.06*			
WMC	.64	.25	1.89	6.68*			
RAT	.64	.24	1.90	7.14**			
Constant	.07	.21	1.07	.10			
Block 2					5.40*	38.17**	.36
Antisaccade	.63	.26	1.88	5.93*			
WMC	.60	.25	1.82	5.63*			
RAT	.54	.25	1.72	4.88*			
Completeness	.54	.24	1.71	5.03*			
Constant	.07	.22	1.07	.11			

Note: * $p < .05$, ** $p < .01$

did not fall within the resulting confidence interval of the bootstrapped indirect effect, one can conclude that there is a significant mediation effect to report. That is, at least some of the relationship between RAT performance and spontaneous transfer can be explained via differences in summary completeness. A one-tailed non-bootstrapped Sobel test of this effect was also marginally significant, $B = .13$, $SE = .08$, $z = 1.61$, $p = .054$. While including a measure of the quality of the story representation improved the fit and slightly reduced the relationship between RAT scores and spontaneous transfer, the direct path for RAT scores (the relationship between RAT and transfer controlling for summary completeness) remained significant, $B = .54$, SE (bootstrapped) = .25, 95% CI = .06–1.03. This last result indicates that not all of the relationship between RAT performance and spontaneous transfer can be explained via differences in summary completeness. Thus, these analyses suggest *partial* mediation by the quality of the story representation in explaining how individual differences in remote associative ability facilitated the spontaneous generation of the convergence solution.

Individual differences and rated helpfulness of lightbulb story

Ratings of helpfulness ranged from 1 to 10, with an average rating of $M = 8.03$ ($SD = 2.26$). Table 5 presents the results of the hierarchical regression predicting participants' ratings of Lightbulb Story helpfulness, which served as a measure of mapping. When all three measures were entered at once, WMC was a significant predictor, while RAT scores were marginal ($p = .08$). While the ability to make remote associations was particularly important for the quality and spontaneous use of the source story representation, WMC was particularly important for mapping (as measured by helpfulness ratings).

Discussion

Based on prior work it was expected that individual differences in the ability to control one's attention (as measured by antisaccade and WMC tasks) would predict spontaneous generation of the convergence solution on Duncker's Radiation Problem following exposure to a relevant

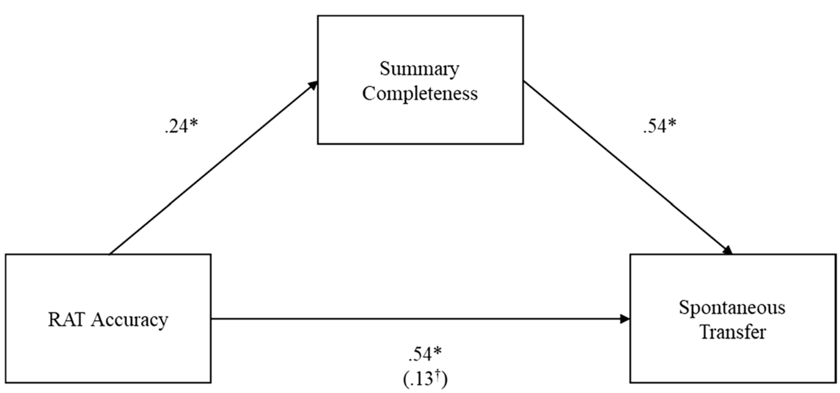

Fig. 2 Relationship between RAT and Spontaneous Solution with Summary Completeness as a mediator, controlling for Antisaccade and WMC. Number in parentheses represents the indirect effect

Table 5 Hierarchical regression predicting rated lightbulb story helpfulness

	B	*SE*	β	*T*	R^2	*F*	ΔR^2	ΔF
Block 1					.13	8.58**		
Antisaccade	.40	.21	.17	1.91†				
WMC	.59	.21	.26	2.84**				
Constant	8.03	.20		41.28**				
Block 2					.15	6.90**	.02	3.20†
Antisaccade	.30	.21	.13	1.40				
WMC	.51	.21	.23	2.45*				
RAT	.38	.21	.17	1.79†				
Constant	8.03**	.19		41.66**				

Note: † $p < .10$, * $p < .05$, ** $p < .01$

analogical source that included that solution. This prediction was made on the basis of prior research indicating that attentional control should be beneficial for source representation and mapping processes. In addition, this correlational study also tested whether a measure capturing individual differences in the ability to make remote associations (the RAT) would also help to predict transfer as it might benefit the individual's ability to notice the relevance of the dissimilar source. Individual differences in both attentional control and the ability to make remote associations were predicted to have facilitative effects on analogical problem solving.

These predictions were supported in regards to spontaneous transfer from the Lightbulb Story to the Radiation Problem. Measures of both attentional control and the ability to make remote associations predicted spontaneous generation of the convergence solution during initial attempts to solve the Radiation Problem. The hierarchical regressions suggested unique and additive roles for measures of both constructs. This is consistent with the idea that, while focused attention is important for some aspects of analogical transfer, the ability to make remote associations may also benefit noticing and use of relevant analogs. Specifically, it was found that WMC was particularly important for mapping (as measured by helpfulness ratings), while the ability to make remote associations was particularly important for the quality and spontaneous use of the source representation.

It was also hypothesized that measures of attentional control should predict the quality of source representation. However, measures of controlled attention were not significant predictors of summary completeness. Rather, success on the RAT was the only significant predictor of completeness. This result was somewhat unexpected as WMC, and the closely related construct of fluid intelligence, have been found to relate to advantages in the construction of text and problem representation (Andersson, 2007; Daneman & Carpenter, 1980; Friedman & Miyake, 2000; Kubricht, Lu, & Holyoak, 2016; Singer & Ritchot, 1996; Swanson, Cooney, & Brock, 1993; Thevenot & Oakhill, 2006; Turner & Engle, 1989). However, in the present study participants were able to look back at the Lightbulb Story when writing their summaries, which may have altered the role that individual differences in attentional control could play in representation while also enabling a relationship between the ability to make remote associations and summary completeness.

Another possible explanation for these results is that the ability to control attention is not, by itself, sufficient for that person to develop a representation of a source that will lead to transfer. For example, a greater ability to focus attention may actually be detrimental if that attention is focused on the wrong aspects of the source story (Beilock & de Caro, 2007; Ricks, Turley-Ames, & Wiley, 2007). It may be more important to understand how the ability to control attention interacts with either the demands of the task or the individual's predisposition towards a particular mode of thinking or interpreting information. However, the present results suggest that it was the participants who were better at finding remote associations, who included more elements of the story in their summaries, who were later in a better position to transfer the solution offered by the analog.

Under exactly which conditions and in precisely what way individual differences in the ability to make remote associations might help to facilitate analogical transfer is an area that merits future research. This study represents a first attempt to demonstrate a unique role for this ability in predicting transfer from the Lightbulb Story to the Radiation Problem. It is entirely possible that the relative influence of individual differences in attentional control and the ability to make remote associations on problem solving success will vary depending on the specific demands of the transfer task, and may not generalize to other problem solving contexts. For example, task demands may vary due to the extent of superficial similarity between the source story and the target problem (Holyoak & Koh, 1987), exposure to multiple sources providing a convergence solution (Catrambone & Holyoak, 1989; Gick & Holyoak, 1983; Kurtz & Loewenstein, 2007), or exposure to multiple sources providing a variety of solutions (Gick & Paterson, 1992). Additionally, this study required participants to summarize the source information that they had been presented. This was done both because it is a common part of the analogical transfer design as it has been used in the past (e.g., Francis, 1999; Gick & Holyoak, 1980), and also because we were interested in predicting transfer based on those summaries. However, it is possible that the act of writing a summary of the source could have influenced the relationship between the individual differences variables and transfer. Future research could compare the relationships as a function of having to write versus not having to write a summary of the source.

This work helps to build on other research examining the role of individual differences in analogical thinking (e.g., Morrison et al., 2004; Richland et al., 2006, 2010) and analogical transfer (Kubricht, Lu, & Holyoak, 2016), using individual differences measures not previously examined in the analogy literature. The use of multiple measures in this area of research is important to establish convergent validity as to what constructs are relevant for transfer. Toward that end, future research could extend this work with yet other measures. For example, future research may want to include more language-based measures of controlled attention, such as Reading Span tasks, or an independent measure of reading ability. This could help to assess the degree to which skill in reading, linguistic, or verbal ability is predictive of spontaneous transfer. The RAT task is a fundamentally verbal task, requiring participants to identify distant associates of multiple words. Although the finding that RAT scores are a significant predictor of spontaneous transfer after controlling for summary completeness (another language-based measure) suggests there is more to the relationship, it is possible that the linguistic nature of the RAT task is helping to strengthen its relationship to the spontaneous transfer of a written source to a written problem. Latent inhibition tasks would provide another interesting alternative measure. Latent inhibition tasks have been used previously in investigating the relationship between broader attention and creative ability on divergent thinking tasks (e.g., Carson, Peterson, & Higgins, 2003). Latent inhibition tasks measure the degree to which people make use of information that is presented outside of the focus of attention. Individuals with low latent inhibition are less able to ignore peripheral information and more likely to make use of that information. It would be interesting to test if this construct might also be related to an increased likelihood of spontaneous analogical transfer.

Another promising direction may be to investigate whether the ability to mix or switch between attentional modes might predict better transfer. Just because a person is able to perform well on a controlled task does not necessarily mean that they are able to switch from a more focused state of attention to a more diffuse mode when necessary. The propensity to think broadly, or the ability to flexibly switch between more and less controlled modes, may represent other capabilities that are relevant to predicting successful analogical transfer. Exploring such abilities may help to explain why RAT performance is a good predictor of spontaneous transfer, as it also requires solvers *both* to make broad associations and to focus and identify singular correct answers. Moreover, the potential benefits that may come from mixing broad and focused attention are consistent with several theories of creative thinking (e.g., Guilford, 1957; Martindale, 1995) including insightful problem solving (Wiley & Jarosz, 2012). Relatedly, future work might explore whether participants perceive their solutions on RAT problems as coming from insight versus analysis (Bowden & Jung-Beeman, 2003a), and whether that affects the relation of RAT performance to spontaneous analogical transfer. Future research might also explore Duncker's original observation that some of his participants seemed to solve analogical transfer problems with insight (1926, p. 686), and to test whether self-reports of Aha! or insightful versus analytic solutions relate to the way that attention predicts spontaneous transfer (George & Wiley, 2018).

Conclusion

The present results affirm that the likelihood of spontaneous transfer depends critically on the quality of the representation for the source analogy, but also suggest that individual differences in the ability to make remote associations may be conducive to analogical transfer (including in constructing a broader representation of that source). Not only was performance on a Remote Associates Task a significant predictor of spontaneous transfer, but it was also *uniquely* predictive after entering measures of attentional control into a regression. Moreover, RAT scores were also a significant predictor of the quality of source representation. All of these findings support the hypothesis that the ability to make distant connections may be an important component of analogical transfer. These results and the limited role that was seen for attentional control are also consistent with theories of creativity that have suggested that too much attentional control or focus can sometimes be detrimental for creative thinking; that benefits can arise from more diffuse attentional states (e.g., Amer, Campbell, & Hasher, 2016; Ansburg & Hill, 2003; Baird et al., 2012; Mednick, 1962; Wiley & Jarosz, 2012); and that innovative thinking requires a combination of multiple modes of thinking (Guilford, 1957; Martindale, 1995). The present work extends those theories into the area of analogical transfer.

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