Analogical Problem Solving:
A Common Explanation, but a Rare Observation

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THESIS

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This work is dedicated to my father, Joseph P Cushen Jr., who always believed in my ability and took personal pride in my success.

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

SUMMARY

Given the widespread belief that analogical processing is an important mechanism for creative problem solving, but a lack of evidence for 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 research explored the relationships between individual differences in a range of executive functions and abilities, source representation, and 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 focused and diffuse attention, as well as representation quality, predicted spontaneous transfer between a superficially dissimilar source and target.

I. INTRODUCTION

Every problem that an individual faces on a daily basis is in some way unique; otherwise, it would not be a "problem." Perhaps the individual has never seen 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. A solution process that consists of recalling a relevant prior experience and drawing inferences to solve a current problem is typically referred to as "analogical transfer." Because of its ubiquity, analogical processing is considered a primary method for creative problem solving, with Spearman (1923) once suggesting that all acts of intelligence incorporate analogy.

Yet, most laboratory studies examining analogical transfer in problem solving find that people fail to spontaneously use relevant, previously-presented information unless they have been told about that relevance (Barnett & Ceci, 2002; Francis, 1999; Gick & Holyoak, 1980, 1983; Reeves & Weisberg, 1994). In most laboratory studies in this literature, the goal is for participants to identify a relevant analogy based on structural overlap between a source and a target (Gentner, 1983), where structural overlap refers to the degree to which the source and target share similar relations and systems of relations. Instances of spontaneous analogical retrieval, however, seem to be most commonly driven by superficial overlap between the source and the target and only to a lesser degree by the structural overlap. The dominance of superficial similarity in retrieval explains the tendency for most analogies to be relatively local, or drawn between very near sources and targets (e.g. Dunbar, 2001). This tendency in retrieval is generally beneficial, as information or experiences that share many superficial characteristics often share many structural characteristics as well (Blessing & Ross, 1996). Unfortunately, this tendency can also limit an individual's ability to transfer information from prior instances and ultimately may

lead to a failure to recognize relevant analogies if the analogous source and target are superficially dissimilar.

Given the widespread belief that analogical processing is an important mechanism for creative problem solving, but a lack of evidence for spontaneous transfer, a critical direction for future research is to address what factors may allow for the spontaneous analogizing between distant (superficially dissimilar) sources and targets. The current experiments explore the role of individual differences in executive control and abilities, and their possible differential effects on spontaneous analogical transfer. In this way, these studies attempt to increase the understanding of what conditions encourage the successful transfer of solutions between superficially dissimilar sources and targets.

A. **Phases of Analogical Transfer**

In addressing the relationship between individual differences in executive control and analogical transfer, it is important to recognize that the transfer process actually consists of several stages, each of which may present their own obstacles to success. The process of analogical transfer can be divided into three general phases: representation, noticing/retrieval, and mapping/adaptation of that retrieved solution.

The representation phase refers to the process of encoding both the target problem and the source experience. In order to be able to engage in analogical transfer, the individual needs to not only construct a mental representation of problem to be solved, but also to have attended to a source so as to develop a representation of that source as well. The noticing/retrieval stage represents a memory search process where, in response to the target problem, relevant prior information needs to identified and brought from long-term (or secondary) memory into working

memory. In experimental studies of transfer, these sources are typically presented to participants within the same experimental period as the problem. The goal is for the participant to spontaneously retrieve previously presented material and notice its relevance. Finally, retrieval is followed by a mapping process in which correspondences between the source and target are determined and an optimal analogy is selected. Additionally, information may need to be adapted in order to provide a solution for the target problem. This adaptation normally takes the form of inferences generated from the source to the target, suggesting important yet unrepresented or misrepresented information in the target analog.

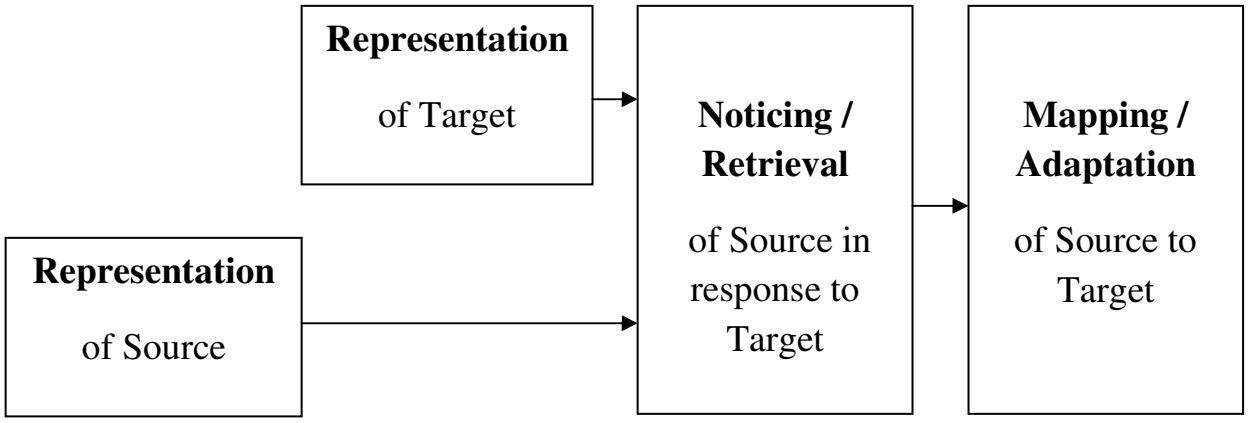

Figure 1. Sequence of analogical transfer in problem solving.

B. **Attentional Control and the Phases of Analogical Transfer**

Some work has already begun to investigate the role of individual differences in executive functioning on analogical transfer. An individual's executive control includes a set of abilities associated with updating the contents of attention, inhibiting irrelevant information, and

switching between tasks (Miyake et al., 2000). The role of individual differences in executive control and attention are of specific interest to researchers insofar as they are general abilities that can influence analogy and problem solving across a variety of content domains. Whereas such things as domain knowledge also certainly play a role in the ability of an expert to identify analogical similarity between a source and target within their domain of expertise (e.g. Ball, Ormerod, & Morley, 2004; Bearman, Ball, & Ormerod, 2007; Novick, 1988; Novick & Holyoak, 1991), measures of attention may be more likely candidates to predict cross-domain transfer, or transfer in poorly-understood domains, due to their domain-general nature. As such, the goal of this research is to investigate the role of these domain-general abilities in analogical transfer.

Prior research in this area has emphasized the role of this control in the mapping stage (Chuderska &Chuderski, 2009; Morrison et al., 2004; Richland et al., 2006, 2010; Viskontas, Morrison, Holyoak, Hummel, & Knowlton, 2004; Waltz, Lau, Grewal, & Holyoak, 2000). The other stages of the process have yet to be explored. Work that has already been done on executive function and analogy is considered first, followed by a discussion of theoretical predictions for its influence in the other phases of problem solving.

1. **Mapping/Adaptation**

Recent research has emphasized the role of executive control processes during analogical mapping. In drawing an analogy, the quality of the mapping is determined by the degree to which an individual is able to identify the one-to-one alignment of the important relations in the source to those in the target. The difficulty of this alignment process is exacerbated when the sources and targets contain systems of relations that must be placed in correspondence with one another. However, failure to draw 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 executive control.

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 executive control 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 one common task, the People Pieces task (Viskontas et al., 2004), 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 do the first pair. Viskontas et al. (2004) demonstrate 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 argue that this difficulty is associated with age-related declines in focused attention. Using this same task, Cho et al. (2010) have both 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 focused attention to overcome.

In another common task, scene analogy problems (Morrison et al., 2004; Richland et al., 2006, 2010), subjects are presented with pairs of images depicting objects that stand in some relation 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 have been shown to 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 attribute to deficits in inhibition and working memory. In this same paradigm, Waltz, Lau, Grewal, and Holyoak (2000) have shown that secondary tasks taxing either verbal working memory or executive attention both 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 featural overlap. Finally, Chuderska and Chuderski (2009) have used an individual differences approach to identify correlations between successful mapping of figural analogies (in this case, identifying analogous shapes to a probe shape) and several measures of attentional control, including inhibition and task switching.

Thus, research has provided a great deal of evidence indicating that focused attention is critical to analogical mapping. Specifically, it 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. Unfortunately, the use of paradigms in which both source and target are presented simultaneously preclude investigation of the other phases of analogical transfer including representation and retrieval.

Due to these limitations, a more holistic paradigm has been used to examine analogical transfer. In this classic paradigm (Catrambone & Holyoak, 1989; Francis, 1999; Gick & Holyoak, 1980, 1983; Holyoak & Koh, 1987), participants are presented with one or several

source stories under the guise of a reading task. These stories often describe problem-solving situations and solutions. Participants are then, at a later time or date, presented with a problem that shares structural similarities with the sources presented. Evidence of analogical transfer is considered to be present when participants who had previously seen the analogous sources demonstrate above-baseline use of the solutions suggested by the earlier stories. Successful transfer in this paradigm requires participants to represent the information in the source analogs, to notice the relevance at the point of problem solving and retrieve that prior source from memory, and then *finally* to map the relationships between the sources and target problem so as to enable the transfer of the solution.

2. **Representation**

The above paradigm demonstrates greater ecological validity, but has never been used in conjunction with an individual differences methodology to examine the role of attentional control across the entire analogical transfer process. This means that an understanding of the influence of individual differences in attention across the transfer process and within many of its component process is still lacking. For example, the role that attentional control plays in supporting the representation of the source and target cases has largely been ignored within the analogy literature.

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 that individual's likelihood of spontaneously using the source for later problem solving (Gick & Holyoak, 1983). 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, in a classic analogical transfer experiment, Gick and Holyoak (1983) had participants read and compare similarities between two analogous sources both suggesting a "convergence" strategy. The authors believed that this 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. Further, those individuals who were considered to have the best schematic representation of the convergence strategy demonstrated the highest rates of transfer. Catrambone and Holyoak (1989) found that greater benefits to transfer can be obtained from simply providing scaffolding questions that guide 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 to the likelihood of later transfer (Bearman, Ormerod, Ball, & Deptula, 2011). Ultimately, these studies suggest that the optimal representation to facilitate transfer is one that emphasizes the structure of the source or target. Therefore, one might predict that those individuals who are best able to represent information at multiple levels of abstraction (both superficial and structural) will be most likely engage in spontaneous transfer.

Indeed, there is evidence that attentional control may facilitate the construction of representations that include both surface and structural information. Within the literature on text comprehension, an individual's ability to generate inferences and understand the meaning of a text has been related to his or her working memory capacity (e.g. Daneman & Carpenter, 1980; Friedman & Miyake, 2000; Singer & Ritchot, 1996; Turner & Engle, 1989). Working memory capacity, as measured by span tasks, has been suggested to depend largely on an individual's

ability to control attention (Conway et al., 2002; Engle, 2002). As such, better attentional control is suggested to help readers not only retain more information from the texts, but to construct multiple representations of text including both surface models and situation models. This suggests that solvers with better attentional control may be better able to represent both superficial and structural aspects of the source and target cases.

Prior research has frequently demonstrated an important role of executive functioning in determining the quality of a problem representation during problem solving. In mathematical word problem solving, measures of attentional control 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 attentional control conferring advantages to either problem representation or calculation ability (Swanson, Cooney, & Brock, 1993). Thevenot and Oakhill (2006) have demonstrated that the way word problems are represented by solvers is influenced by working memory capacity. Further, Andersson (2007) found that measures of working memory continue to predict performance on word problems even after performance on formulaic arithmetic problems is controlled, indicating an added benefit to representation. Finally, Passolunghi et al. (1999) suggest that those individuals with higher attentional control perform better on word problems due to an inhibition of irrelevant information within the problem statement. In sum, these results suggest that controlled attention may facilitate the representation process, perhaps by allowing for the encoding of more information within a single representation, the generation of multiple levels of representation, or the abstraction of structural information from text.

It remains an open question as to whether attentional control will influence the representation stage in such a way as to improve the likelihood of spontaneous transfer. If

controlled attention is related to the ability to construct a higher quality representation of a source, or a representation that better elaborates the structural aspects of that source, then spontaneous noticing of the analogy should be positively related to this ability. Further, in this case, one could predict that the relationship between controlled attention and spontaneous transfer should be mediated by the quality of the source representation.

3. **Noticing/Retrieval**

There has also been a lack of research on the role of attentional control during the retrieval phase. In paradigms in which the source and target are not presented simultaneously, the noticing and retrieval of the prior source in response to the target problem is *primary* to the successful transfer of information. Indeed, mapping cannot occur without first identifying a potential source.

While it is generally agreed that optimal mapping requires focused attention, the role of attentional control in successful 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). As such, the cases that come to mind most easily may not actually be helpful for solution, as relevant information may lay in a more distant, less similar source.

Given this consideration, two alternate predications may be made regarding the role of controlled attention in retrieving distant sources. First, it may be the case that inhibitory processes are necessary to allow for the ability to ignore the cases that are brought to mind by superficial similarities. If an individual is able to recognize that initially retrieved cases are not

useful towards problem solving, then inhibition may facilitate the suppression of those initial retrievals and allow for other, more dissimilar, sources to come to mind.

Alternatively, focused attention may actually harm one's ability to retrieve distant sources if such sources are inhibited during retrieval. In this case, a more broad or divergent search of memory may be most beneficial for discovering useful analogs. Given that diffusion of attention has been shown to facilitate the identification of remote associations in other paradigms (Ansburg & Hill, 2003; Jarosz, Colflesh, & Wiley, 2012; Mednick, 1962), it is possible that this same diffusion will allow for the consideration of relevant, superficially dissimilar sources.

The contrast between these predictions highlights the possibility that spontaneous transfer, or being receptive to a dissimilar, distant source, may be difficult due to the fact that both focused attention and divergent thinking may both be needed for effective noticing and retrieval. Thus, spontaneous analogical transfer may be difficult to observe because it relies on a rare combination of both convergent and divergent thinking skills within the same individual. Alternately, measures of flexibility, such as those representing efficient task switching, may instead be better predictors of spontaneous use of distant sources than measures of focused attention.

C. **Overview**

These hypotheses were explored in a series of studies. The first study investigated source and target materials to find a combination with a substantial enough solution rate to allow for the investigation of individual differences in abilities and analogical transfer. The second study provided an initial investigation into representation quality and spontaneous analogical transfer.

The third study explored the relation of individual difference measures to various phases of analogical problem solving.

II. STUDY 1

The purpose of Study 1 was to identify source and target materials conducive to examining individual differences in spontaneous transfer. The target problem, Duncker's Radiation (or "Ray") Problem, was selected due to its repeated use in research on transfer (Catrambone & Holyoak, 1989; Francis, 1999; Gick & Holyoak, 1980; 1983; Holyoak & Koh, 1987; Kurtz & Loewenstein, 2007). The Ray Problem reads:

> Suppose you are a doctor faced with a patient who has a malignant tumor in his stomach. It is impossible to operate on the patient, but unless the tumor is destroyed the patient will die.
>
> There is a kind of ray that can be used to destroy the tumor. If the rays reach the tumor all at once at sufficiently high intensity, the tumor will be destroyed. Unfortunately, at this intensity the healthy tissue that the rays pass through on the way to the tumor will also be destroyed. At lower intensities the rays are harmless to healthy tissue, but they will not affect the tumor either.
>
> What type of procedure might be used to destroy the tumor with the rays, and at the same time avoid destroying the healthy tissue?

The intended solution to this problem is the suggestion that many weak rays, applied from multiple directions simultaneously, will converge with enough power to destroy the tumor without harming any surrounding tissue. The target problem was the same for all conditions, but the number and type of sources provided varied across conditions.

A. **Method**

In total, six conditions were tested. In one condition (No Story; N = 21), subjects were simply given the Ray Problem without exposure to any prior story. Subjects were given 5 minutes to generate possible solutions to the Ray Problem. After 5 minutes, participants were asked to stop solving and rate the Ray Problem on understandability. They were then given another 5 minutes to generate additional solutions.

In the second condition (Irrelevant Story; N = 19), subjects were first presented with an irrelevant story under the guise of a "reading task." This story, "The Wine Merchants," (Gick & Holyoak, 1980; 1983) does not present an analogous situation to the Ray Problem. It is included in Appendix A.

Subjects were given 3 minutes to read the story. After reading, they were asked to rate the story on understandability and spend 5 minutes writing a summary. Subjects were allowed to look back at the story while writing the summary. After finishing the summary, the story materials were collected and subjects were told they were now going to complete a "problem solving task." The Ray Problem was then distributed and the procedure was the same as in the no-story condition.

In the third condition (General Story; N = 19), subjects were presented with a relevant story, "The General" (included in Appendix A), prior to attempting the Ray Problem. Subjects were asked to read, rate, and summarize the story. After the summaries were written, the story and summaries were collected and participants were given the Ray Problem as a "problem-solving task." Participants were given five minutes to generate solutions to the Ray Problem. After this initial attempt, they were asked to rate the understandability of the Ray Problem and

were instructed as to the potential usefulness of the prior story in solving the problem. They were then given another five minutes to generate more solutions. This prompt to consider the usefulness of the prior story is the "hint" that has been traditionally used in this research (Francis, 1999; Gick & Holyoak, 1980).

Finally, participants completed the ray problem questionnaire, which directly prompted participants to indicate the solution to the Ray Problem that was suggested by the story or stories that they read previously. The questionnaire also asked participants to rate how helpful they considered each story to have been to problem solving on the Ray Problem on a 1-10 scale.

In the fourth condition (General & Fire Chief Stories, N = 32, included in Appendix A), subjects were presented with both "The General," and a second, analogous story, "The Fire Chief." Subjects first read, rated, and summarized "The General." They then read "The Fire Chief," rated it, and summarized it in the same manner. The Ray Problem was then distributed and the procedure was the same as in "The General" story condition.

In the fifth condition (Comparison; N = 41), subjects read both "The General" and "The Fire Chief" as in the prior condition, but were additionally asked to take 5 minutes to describe in writing the ways in which the two stories were similar. After completing the comparison essay, all participants completed the Ray Problem procedure as in "The General" story condition.

In the sixth condition (Lightbulb; N = 46), subjects read "The Lightbulb," (Holyoak & Koh, 1987, included in Appendix A). With the exception of the new story, the experimental procedure was identical to that of the "The General" story condition.

B. **Results**

The primary outcome of interest was a participant's spontaneous generation of the convergence solution. Table 1 presents rates of generation of this convergence solution for all conditions. In addition, participant's ability to generate the solution suggested by the story or stories when directly prompted (prompted retrieval) on the questionnaire was also examined. Whereas spontaneous generation of the convergence solution represented the ability of a participant to spontaneously transfer from source to target, prompted retrieval removed the need of participants to notice the relevance of the prior story themselves and provides a measure of participants' abilities to recall and make use of prior sources in the absence of noticing. Finally, rated helpfulness of each source was examined as a measure of participants' subjective assessments of the quality of the mapping between the source and target. Individuals capable of drawing the connections between the solution suggested by story and the problem posed by the Ray Problem should rate the story as having been more helpful in solving. As such, rated helpfulness should provide a measure of an individual's ability to identify the mapping between the source and target.

1. **Spontaneous Generation**

Spontaneous generation of the convergence solution was quite low in most conditions. Only 5% (1 individual) in the No Story condition and 16% (3 individuals) in the Irrelevant Story condition spontaneously generating it as a possible solution to the problem. This rate of spontaneous generation is similar to the low rates identified in previous studies (e.g. 10% in Gick & Holyoak, 1983). In the General, General & Fire Chief, and Comparison conditions, spontaneous generation rates were 0%, 6% (2 individuals), and 7% (3 individuals) respectively.

Spontaneous generation of the convergence solution did not differ significantly across these conditions, $x^2(1, N = 132) = 3.97, p = .41$.

However, in "The Lightbulb" condition, spontaneous use of the convergence solution was 59% (27 individuals). This rate of convergence solution use is well above the rate of 16% (seen when subjects were presented with the irrelevant Wine Merchant story prior to problem solving), $x^2(1, N = 65) = 9.96, p = .002$, and is evidence of spontaneous analogical transfer between "The Lightbulb" and the Ray Problem.

2. **Prompted Retrieval and Use**

The final questionnaire prompted individuals to indicate what solution to the Ray Problem was suggested by the story or stories presented earlier. Participants were given credit for correct generation of the convergence solution to this prompt only if they framed their response in terms of the Ray Problem solution suggested by the story.

When directly prompted in this way, 37% (7 individuals), 42% (13 individuals), and 61% (25 individuals) indicated that the convergence solution to the Ray Problem as having been suggested by one or both of the stories in the General, General & Fire Chief, and Comparison conditions, respectively. In the Lightbulb condition, 83% of individuals provided the convergence solution in response to the prompt. This rate of prompted generation was significantly higher than the rates identified in any of the other conditions, $x^2(1, N = 87) = 5.08, p = .02$ (relative to the Comparison condition). Table 1 shows generation of the convergence solution as a function of each story within each condition. The greater rate of generation of the convergence solution when prompted relative to the rate of spontaneous solution in each condition, $F(133) = 71.10, p < .001$, suggests that many subjects have access to and are capable

of making use of the information presented previously, but do not spontaneously notice the relevance.

3. **Mapping Ability**

The final outcome of interest was how helpful participants rated the source as having been in solving the task. This was used as an indicator of participants' recognition of the mapping between the source and target. Table 1 summarizes the helpfulness ratings for each source as a function of condition. Collapsing across conditions, participants rated the helpfulness of the Lightbulb story as significantly higher than the helpfulness of either the General story (collapsed $M = 6.73$, $SD = 2.75$), $t(106) = 3.05$, $p = .003$, or the Fire Chief story (collapse $M = 6.12$, $SD = 2.73$), $t(94) = 4.20$, $p < .001$, suggesting that participants identified the story as more relevant to the solution of the Ray Problem than either of the other analogous sources.

Given that the goal of the present line of research is to investigate the effect of individual differences in executive functions on spontaneous analogical transfer, it is important to use a condition with a high enough level of performance to allow for the testing of predictors. The greater-than-baseline rates of spontaneous solution in the "The Lightbulb" story condition suggest that it is resulting in transfer of the convergence solution during later problem solving. As such, "The Lightbulb" story was used as a source in the remaining studies.

TABLE I

RATES OF SPONTANEOUS SOLUTION, PROMPTED RETRIEVAL, AND RATED STORY HELPFULNESS ACROSS STORY CONDITIONS IN STUDY 1

Story Condition	N	Spontaneous Solution	Prompted Retrieval	Rated Helpfulness
No Story	21	5% (1)		
Irrelevant (Wine Merchants) Story	19	16% (3)	0%	5.14 (1.77)
General Story	19	0% (0)	37% (7)	6.67 (3.14)
General & Fire Chief Stories	32	6% (2)		
General Story			35% (11)	6.10 (2.98)
Fire Chief Story			29% (9)	6.10 (2.16)
Comparison	41	7% (3)		
General Story			49% (20)	7.13 (2.45)
Fire Chief Story			54% (22)	6.13(3.06)
Lightbulb Story	46	59% (27)	83% (38)	8.17 (1.96)

Note. Parenthesized values in rated helpfulness represent standard deviations.

III.STUDY 2

The purpose of Study 2 was to explore the relationship between representation quality and spontaneous transfer through coding of each individual's story summaries on the Lightbulb Story, obtained in Study 1. (See Appendix B for "The Lightbulb" coding sheet.)

An analysis of the contents of the Lightbulb story yielded 8 essential concepts that a participant might include in their summaries:

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)

Three of these concepts have been previously identified as critical components to the convergence solution, and have been considered as part of a "convergence schema" (Catrambone & Holyoak, 1989; Gick & Holyoak, 1983). These elements include (1) the use of many weak forces (SC4), (2) spatial convergence (SC5), and (3) temporal convergence (SC6). Thus, based on previous work one measure of representation quality can be computed by taking the proportion of these "convergence schema" concepts mentioned out of the possible set of 3.

The additional 5 concepts summarize the remaining content of the story (including the antecedents and consequences of using the convergence solution). Moreover, by coding participants' summaries for all 8 concepts, this coding allows for the quantification of both

overall representational quality (proportion of concepts included out of the possible 8) as well as the identification of other concepts that may predict spontaneous transfer.

A. **Method**

Two coders read the story summaries and identified the presence of absence of each of the 8 concepts. Inter-rater reliability was high (.74), with disagreements resolved by a third coder.

B. **Results**

The strongest predictor of spontaneous transfer was found to be the inclusion of the concept, "A high-intensity ultrasound wave would also break the glass," (SC2; a constraint on solution in the story). Logistic regression found that the inclusion of this factor significantly improved the likelihood of spontaneous transfer, $x^2(1, N = 46) = 14.65$, $p < .001$. Inclusion of this concept also resulted in a higher likelihood of success at prompted retrieval, $x^2(1, N = 46) = 5.08$, $p = .02$, and in the story being rated as more helpful, $F(1, 44) = 7.44$, $MSE = 3.36$, $p = .01$.

The completeness of the story summary (out of 8) also significantly predicted both spontaneous transfer, $x^2(1, N = 46) = 5.73$, $p = .02$, and marginally predicted both prompted retrieval, $x^2(1, N = 46) = 3.72$, $p = .054$, and rated helpfulness of the story, $F(1,44) = 3.48$, $MSE = 3.64$, $p = .07$. Despite being prior research suggesting its criticalness to spontaneous transfer (e.g. Catrambone & Holyoak, 1989; Gick & Holyoak, 1983) the completeness of the convergence schema (out of 3) did not predict any of the relevant outcomes.

TABLE II

CORRELATIONS BETWEEN STORY CONCEPTS, MEASURES OF REPRESENTATION QUALITY, AND TRANSFER AND MAPPING

Measure	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	Conv Schema	Total Sum	Spont Trans	Prompt Retriev	Story Help
SC1	-	.44**	.15	.05	.17	.06	.04	.13	.13	.46**	.49**	.23	.31*
SC2		-	.14	.28	.12	.31*	.24	.23	.32*	.60**	.55**	.35*	.38**
SC3			-	.49**	.41**	.19	.15	.23	.52**	.60**	-.04	.22	.26
SC4				-	.20	.23	.139	.21	.67**	.56**	-.02	.17	.16
SC5					-	.41**	.61**	-.01	.77**	.65**	.18	.21	-.06
SC6						-	.49**	.14	.72**	.60**	.19	.08	.15
SC7							-	.13	.58**	.62**	.22	.00	-.14
SC8								-	.15	.46**	-.01	.04	.20
Convergence Schema									-	.84**	.16	.22	.11
Total Summary										-	.35*	.28†	.27†
Spontaneous Transfer											-	.43**	.37*
Prompted Retrieval												-	.63**
Story Helpfulness													-

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

While this overlap may explain the significant transfer from the Lightbulb story, its absence may also explain why the other stories piloted did not result in similar levels of transfer. For example, the classic General story states the constraint on using a large force as, "...any large force would detonate the mines. Not only would this blow up the road, but it would also destroy many neighboring villages." This version of the constraint, that use of a large force would destroy neighboring villages, is stated with less superficial similarity, and with greater complexity, than in the Lightbulb story. Moreover, in the Fire Chief story, the constraint on problem solving (i.e. there was no means to deliver a strong force from a single source) is entirely different than that present in the Ray Problem. This additional lack of overlap may explain its relatively poor facilitation of transfer in Study 1. Finally, both the General and the Fire Chief stories are devoid of a concept analogous to SC8, essentially a reminding about how the final strategy avoided the problem-solving constraint. The presence of this final reminder only in the Lightbulb story may help to ensure that the constraint is noticed and ultimately recalled during solving of the Ray Problem.

If this prediction is accurate, then inclusion of the constraint statement in story summaries for the General or Fire Chief story may reflect this lack of emphasis. However, clear inclusion of the constraint statement should nevertheless facilitate transfer from the General story (where the constraint is analogous), but may have little impact on transfer from the Fire Chief story (where it is not analogous).

IV. STUDY 3

The purpose of Study 3 was to explore how individual differences in executive control are related to spontaneous analogical transfer. This study included measures of inhibition, working memory capacity, susceptibility to distraction, divergent thinking, and attentional flexibility. The results of this study will be discussed in three steps. First, a descriptive and qualitative analysis of the individual differences measures will be presented. Second, composite measures representing focused attention and diffuse attention will be obtained by separately extracting a single source of common variance from the sets of focused and diffuse tasks. A factor representing flexibility derived from task-switching tasks will also be considered. Finally, these factors will be used to predict problem-solving performance via hierarchical regression. These regressions will all follow the same pattern of entering each factor into the regression in a separate block. Changes in model fit as a function of block will be discussed as indicative of the added contribution of each factor.

The primary dependent variable of interest in this investigation was spontaneous generation of the convergence solution, first presented in the Lightbulb story, while solving the Ray Problem. Prior research has suggested that focused attention is critical to analogical mapping. However, it remains an open question as to whether focused attention will remain predictive across the whole analogical transfer process or if another individual difference will be more predictive. I predict that a role for focused attention will be seen in spontaneous transfer, as such transfer does require mapping the source to the target. However, I also suggest that an additional role should be seen for diffuse attention, as less focused attention has been associated with the ability to notice and retrieve more distant associates to target information.

In addition to spontaneous transfer, the influence of these factors on prompted retrieval and mapping ability (as measured by rated story helpfulness) will also be assessed. As described in Study 1, both of these measures eliminate the need for spontaneous noticing of source relevance. Given the prior evidence for the role of focused attention in analogical mapping, the focused attention factor should appear as a significant predictor for the mapping measure. For the prompted retrieval measure, since memory is being prompted, access to the prior story may also depend on the focused attention factor. In an analysis using the story summaries, the individual difference factors will be used as predictors for several measures of representation quality, including the mention of the constraint (SC2), the completeness of the convergence schema, and the completeness of the summary. There is reason to predict that measures of focused attention should predict representation quality. Moreover, because of the overlap between reading ability and focused attention, both constructs will be included in regression models.

Finally, the impact of representation quality on spontaneous transfer will be assessed, with the expectation that the quality of representation should predict spontaneous transfer. If any individual difference factors are found to relate both to spontaneous transfer and representation quality, analyses will be conducted to assess whether the influence of that factor on spontaneous transfer can be explained as a function of representation quality.

A. **Method**

1. **Participants**

One-hundred and forty-one undergraduates were recruited from the University of Illinois at Chicago subject pool in exchange for course credit. Participants averaged 19 years of age. Sixty-two percent of the individuals in the sample were female. Seventy-two percent of the

sample reported speaking multiple languages fluently. Appendix C presents differences in performance on attention measures and analogical transfer as a function of language group. Because no differences were seen, language groups are collapsed in the analyses reported below.

2. Materials

The materials for this study were the "The Lightbulb" story and the Ray Problem used by Koh and Holyoak (1987). Participants were also asked to completed the Ray Problem questionnaire, which requested subjective reports of whether participants attempted to use the source story prior to the hint, ratings of how helpful they believed the story to be in generating a solution, what the solution suggested by the story was, and a report of whether they had seen a problem similar to the Ray Problem previously. (See Appendix D for full analogy materials.) Demographic information was obtained in a survey administered during mass testing that included age, gender, and linguistic background.

3. Procedure

The analogical transfer procedure was identical to that of condition 6 in Study 1, with subjects reading the Lightbulb Story and then being asked to solve The Ray Problem. After the problem-solving phase, all participants completed the Ray Problem questionnaire.

Individual difference measures were collected in the same 2-hour session, following the analogical transfer procedure. The selection of measures was intended to cover abilities in focused attention (updating and inhibition), diffuse attention (divergent thinking and sensitivity to peripheral cues), and flexibility (task switching). The focused attention measures included Operation Span, Symmetry Span, accuracy in the Antisaccade target detection task, accuracy in Reading with Distraction, and reaction time on the Navon Shape-Recognition task. The divergent

thinking measures included number of solutions on a Remote Associates Task and number of solutions an Anagram task that included hinted and non-hinted anagrams. The flexibility measures included switching and mixing costs on the Navon Shape-Recognition task and on a Visual Search task. The tasks were completed in the following order for all participants: Remote Associates Problem Solving, Visual Search, Reading with Distraction, Navon Shape-Recognition, Anagram Problem Solving, Antisaccade Target Detection, Symmetry Span, and Operation Span.

Antisaccade Task. Antisaccade provides a measure of a participant's ability to direct their attention. This task requires participants to inhibit a prepotent response to look towards a visual cue that flashes on one side of a computer display and instead look towards the opposite side in order to detect the target stimuli. The task 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. After a 400 msec delay, a fixation cross appeared at the center of the screen and remained for between 200-2200 msec. After the fixation cross left the screen, a white "=" flashed (100 msec on, 50 msec off, 100 msec on, 50 msec off) in either the right or left side of the screen. A letter was then presented on the opposite side of the screen for 100 msec. This letter was either a "B," "P," or "R." After the letter had been presented for 100 msec, it was masked by the letter "H" for 50 msec and then by the number "8." This last item remained on screen until participants responded with a button press as to which letter they were presented. After they responded, they were presented with a blank screen for 400 msec and then with the ready screen to begin the next trial.

Failure to inhibit the automatic response to look at the initial flashing symbol on one side of the screen makes it difficult for participants to identify which letter was presented on the

opposite side. As such, participant response accuracy can be used as a measure of inhibitory ability, as the more likely an individual was to inhibit themselves from looking towards the flashing symbol, the more likely they were to accurately identify the presented letter. Overall accuracy was computed for each participant as the proportion of correct responses 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). This correction is used to compute all odd-even reliabilities.

Symmetry Span and Operation Span. Two complex memory span tasks were completed by participants. Performance on these complex span tasks has been related to an individual's ability to control their attention, or maintain information or goals in memory in the face of interference (Engle, 2002).

Operation Span required participants to remember a list of letters while simultaneously identifying the correctness of arithmetic statements. For example, the subject might read:

IS (8/4) + 6 = 9 ? P

The subject was required to respond whether the equation is correct or not (in this case, not) and then have to remember the letter "P." Symmetry Span required participants to judge whether an image composed of a 8x8 grid of black and white squares was symmetrical or not, and then remember the location of a red square on a 4x4 grid. After subjects were presented with between 2 to 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.

All items were presented on computer, with participants recording their responses on paper. As suggested by Conway et al. (2005), these tasks were administered one-on-one, with the

experimenter determining the pace of item presentation. For each task, proportion scores were obtained by averaging across the proportion of correct responses out of possible correct responses in each set. Reliability was high for these tasks, with Cronbach alphas of .83 and .77 for SSpan and OSpan, respectively. A composite working memory capacity score was then obtained by averaging across participants' scores on both tasks.

Navon Object Recognition Task. The Navon task required participants to identify the shape of objects as quickly as possible. The task presented participants with large (global) shapes constructed from a series of smaller (local) shapes. The global shapes were approximately 95 mm in height, centered in the middle of the screen, while the local shapes were approximately 9 mm in height. Participants sat with their heads approximately 1.5 feet away from the monitor.

These smaller shapes could either match the larger shape (congruent) or mismatch the larger shape (incongruent). In this case, the shapes used were circles and squares. So participants could be presented with a circle made of circles, a square made of squares, a circle made of squares, or a square made of circles (see Figure 2).

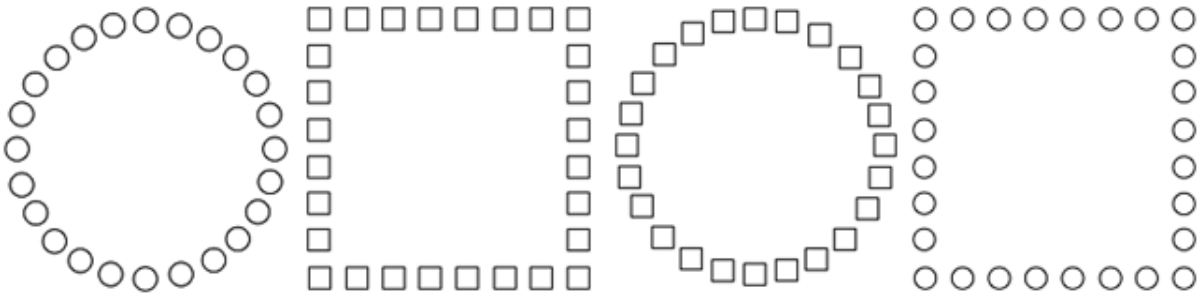

Figure 2. Example Navon object recognition stimuli

Participants were required to identify either the local shapes or the global shape depending on a task cue, as quickly as possible. If the image was presented in blue, participants were required to identify the global shape (in the last example in Figure 2, a square). If presented in black, participants were required to identify the local shape (in the last example in Figure 2, circles).

The task began with 8 alternating "pure" blocks of 8 trials each. In each of these blocks, participants were required to make either only global judgments only or local judgments only, depending on the color of the stimulus. At the beginning of each trial, a fixation cross appeared in the center of the screen for 500 msecs. An array then appeared for which a participant had to judge whether the global or local shape was a circle or square by making a button press with their left or right index fingers, respectively. The array remained on screen until the participant made a shape judgment, then was immediately replaced by the fixation cross for the start of the next trial. In these pure blocks, the trials within a set differed only in congruency (i.e. the consistency between global and local shapes).

Since the Navon Task requires making speeded judgments based on one characteristic of a display (e.g. global shape) while ignoring another feature of that same display (e.g. local shapes, the task includes an inhibitory component, similar to a flanker task. Therefore, average reaction times in the pure blocks were computed for each participant and included as a measure of focused attention. Odd-even reliability for these reaction times was .92.

Further, the degree to which participants were hurt by incongruency between the global and local shapes was predicted to relate to their ability to inhibit irrelevant information. To investigate this possibility, performance on incongruent trials was compared against performance on congruent trials within the pure block by computing a difference score (incongruent minus

congruent trial RTs). In calculating the odd-even reliability of this measure, a marginally negative relationship was identified between odd-calculated incongruency costs and even-calculated incongruency costs, $r(108) = -.19$, $p = .06$ (-.47 Spearman-Brown). This suggests low reliability of this measure. Alternately, the difference in *accuracy* between congruent and incongruent judgments was also calculated. This accuracy difference was more reliable than the reaction time difference (.75 Spearman-Brown). As the measure with higher reliability, only the incongruency cost calculated with accuracy will be considered further.

After these initial blocks, participants completed a "mixed" block of 64 trials. In this block, the type of judgment that participants are asked to make (local versus global) changed randomly, with stimulus color serving as a cue of the appropriate judgment. This resulted in participants sometimes making the same type of judgment multiple times in a row (no switch) and sometimes switching between making local and global judgments. Reaction times for all correct judgments were recorded and used to compute measures of flexibility, including mixing costs (mixed minus pure trial RTs), and switching costs (switch minus no-switch RTs), with lower costs suggesting more flexibility. Odd-even reliability of the mixing costs was .74. Odd-even reliability of the switching costs was .50. As with incongruency costs, mixing and switching costs for accuracy judgments were also calculated. However, these accuracy costs were less reliable (odd-even) than the reaction time costs, with Spearman-Brown coefficients of .57 and .19 for mixing and switching costs respectively. As the measures with higher reliability, only the mixing and switching costs calculated in RT will be considered further.

Reading with Distraction. A Reading with Distraction task was used to assess participant's susceptibility to distraction, as well as their likelihood of attending to peripheral cues in their environment. (See Appendix E for presented texts and Appendix F for problems.)

Several researchers have suggested that diffuse attention relates to creative productivity (Ansburg & Hill, 2003; Carson, Peterson, & Higgins, 2003; Mendelsohn & Griswold, 1966; Seifert, Meyer, Davidson, Patalano, & Yaniv, 1995). This may also relate to the ability to notice distant analogies.

In the task, modeled after Kim, Hasher, and Zacks (2007), participants are first asked to complete a Reading with Distraction task in which they read two stories aloud for comprehension and then complete simple comprehension questions after each story. These stories contain distracting words semantically unrelated to the topic of the stories. Two sets of 10 words (A and B) served as target distractors, with 5 words occurring in each story. These sets were counterbalanced across participants. Each distractor word appeared multiple times in each story, as in the following example:

> *The car ride* house *was getting bumpy* teeth *now that* religious *George had* dodge *left the main* tools *road to use the* airline *dirt road. He* proud *was out of* yearn *school, not having* evoke *to study* river *during the summer* teeth *break. He was* dodge *glad to* male *get out of* yearn *the stuffy* teeth *offices* evoke *of the archaeology* tractor *department* sprinkler *and get out into* river *the field. He* river *always liked going* harp *on archaeology* dodge *digs. He read that* evoke *this dig was trying* sound *to uncover* dodge *some artifacts at a* person *suspected* kayak *Indian burial site. The* yearn *site was located* evoke *near a small lake in* teeth *the back* barrel socks *country. George* yearn *felt the excitement* teeth *building up* river *inside himself. He* dodge *heard the joyous jingle of* yearn *his digging* tailspin *equipment as he hit* evoke *the various bumps* river *and hills* camp *in the road. He* sillouette *smiled eagerly* painting *with anticipation.*

The story is presented in *italics*, with the distracting words presented in normal font. Participants were given 3 minutes to read each italicized story aloud, omitting the distracting text. Reading was audio recorded so that intrusions and exclusions could be identified. Reading times were also obtained for each story. The main measure of distractibility in this task was total number of errors (combining both errors of omission and errors of commission). The number of errors committed in Story 1 was highly correlated to the errors committed in Story 2, $r(118) = .67$, $p < .001$, providing evidence

for split-half reliability (.80) of this measure of focused attention. Further, total reading time across both stories was recorded for all participants and was used in analyses as a measure of reading ability.

Anagram Problem Solving. In this task, participants were presented with 20 anagrams, with 10 seconds to solve each anagram. The solutions to 10 of the anagrams (hinted) were the distracter words presented within the stories. The solutions to the remaining 10 anagrams (control) were from the unused distracter set. The two sets of anagrams were matched for difficulty and were counterbalanced across subjects. Performance on the 10 A-hinted anagrams (M = .56, SD = .19) was correlated to performance on the 10 B-hinted anagrams (M = .57, SD = .20), $r(120) = .39$, $p < .001$ (reliability of .56).

Anagram problem solving has been associated with pop-out solution (Ellis, Glaholt, & Reingold, 2011; Novick & Sherman, 2003), and overall success is thought to depend in part on diffuse attention (Novick & Sherman, 2003). Moreover, the difference between the number of correct hinted versus control anagrams (or the ability to benefit from hints) provided another metric of diffuse attention by measuring an individual's likelihood of benefitting from peripheral cues (Ansburg & Hill, 2003; Mendelsohn & Griswold, 1966).

Remote Associates Problem Solving. The Remote Associates Task (RAT; Mednick, 1962) was presented to participants and was intended to provide a measure of diffuse attention or divergent thinking ability. The task presents participants with problems comprised of a set of three words. For example, a participant may be presented with the following triad:

EIGHT
SKATE
STICK

The participant's goal is to identify a fourth word that forms a compound with each of the three words in the set. (i.e. FIGURE). Performance on this task relies on the ability to move beyond strong semantic associates to each word and to activate common, but remote, associations in long-term memory (Mednick, 1962), and is thought to require diffuse activation or divergent thinking ability (e.g. Ansburg & Hill, 2003; Gibson, Folley, & Park, 2009).

Participants in this study completed 25 RAT items on a computer. (See Appendix G for all problems and solutions). They were presented with one problem at a time and given 30 seconds to generate a solution. Once a solution had been identified, they pressed a button and typed their answer into a text box. Participants' proportion correct served as a measure of their divergent thinking ability.

Visual Search Task-Switching Task. Modeled on the two main search types in the Treisman and Gelade (1980) visual search paradigm, participants in this task were required to identify as quickly and accurately as possible whether a blue X was present in a 7x7 grid of distractor letters presented on a white background. All distractor and target stimuli were 12 mm in height and were separated from other stimuli by a spacing of 20 mm. The goal of each participants was to identify whether the target was present either in a field of blue Os or red Xs (disjunctive search) or in a field of both blue Os and red Xs (conjunctive search). A disjunctive search can be completed rapidly and without attentional control (the target appears to "pop out") while a conjunctive task requires controlled attention to detect the correct convergence of the target features.

Timing of the stimuli were the same as in the Navon task, with trials beginning with a 500 msec fixation cross and with the arrays appearing on screen until participants made a binary judgment about the presence or absence of the target stimulus by making a button press with

either their right or left index fingers, respectively. As in the Navon task, participants first completed 8 alternating "pure" blocks of 8 trials each in which they conduct only disjunctive or conjunctive searches. Finally, participants completed a mixed block of 64 trials in which they were asked to switch between engaging in both types of searches. Switching and mixing costs in this task were used to provide another measure of flexibility, in this case the ability to alternate between attentional states. Odd-even reliability for mixing costs was .50. Odd-even reliability for switching costs was .17. Calculating mixing and switching costs as a function of decreases in accuracy also failed to reveal reliable metrics, with odd-even reliabilities of .16 and .06 for mixing and switching costs respectively. As the measures with higher reliability, only the mixing and switching costs calculated in RT will be considered further.

B. Results

Ten subjects were excluded from all analyses due to reporting of prior exposure to the Duncker Radiation problem on the Ray Problem Questionnaire. If a participant's data were missing or erroneous for only one task, the data for that task were removed from analysis. If a participant's data were missing or erroneous for *multiple* tasks, that participant was omitted from all analyses. Ten individuals were excluded due to issues with two or more tasks. Finally, one individual was excluded from analysis due to a Mahalanobis distance significant at $p = .001$, indicating multivariate abnormality. The remaining sample available for analyses was 120. Descriptive statistics of all relevant individual difference measures are presented in Table 3. Simple correlations between these measures are presented in Table 4.

1. Descriptive Statistics for Focused Attention Measures

Antisaccade Task Accuracy. All participants' data was used for analysis of the Antisaccade task. Participants averaged 81% correct identification, which is similar to the

accuracy rates seen in prior research using identification-based antisaccade tasks (83%, Butler & Zacks, 2006; 87%, Butler, Zacks, & Henderson, 1999). Consistent with prior research demonstrating that high WMC individuals show greater antisaccade accuracy (Kane, Bleckley, Conway, & Engle, 2001), overall antisaccade task accuracy correlated significantly with the composite measure of working memory capacity.

Complex Span Tasks. Four individuals were excluded from Symmetry Span analyses due to a high error rate (less than 85% correct, as suggested by Conway et al., 2005). One additional participant was excluded due to incomplete data. One participant was excluded from Operation Span analyses due to incomplete data. Proportion scores were computed for performance on both SSpan and OSpan. Average performance was typical of that found previously in the UIC population (Cushen & Wiley, in prep). Further, the correlation between SSpan and OSpan, $r(114) = .44$, $p < .001$, was similar to that found in prior research including these tasks (.44, Cushen & Wiley, in prep; .55, Kane et al., 2004).

These proportion scores were averaged to form a composite measure of working memory capacity (Conway et al., 2005). As mentioned above, the composite span measure showed the expected relation with antisaccade (Kane et al., 2001).

Reading with Distraction Errors. One individual was excluded due to an error with the Reading with Distraction task. Participants committed an average of 14.10 errors ($SD = 27.03$) across the reading of both stories. Errors on Story 1 ($M = 9.30$, $SD = 18.92$) were more common than errors on Story 2 ($M = 4.86$, $SD = 10.34$), $F(1, 117) = 11.04$, $MSE = 101.84$, $p = .001$. Consistent with the assumption that distractibility relates to the control of attention, errors on this task correlated with both antisaccade accuracy and composite span score.

Navon Object Recognition RTs. Because the primary measures of interest from the Navon tasks are reaction times, participants were excluded from analyses if their overall judgment accuracy in the task was below 80%. As such, 11 participants were excluded from Navon analyses. Additionally, data was missing for 1 subject due to a computer error. Average accuracy, after trimming these individuals, was .95 (*SD* = .05). Overall reaction time on the pure blocks (containing both congruent and incongruent items) was significantly related to both antisaccade accuracy and composite span scores, suggesting that performance on Navon tasks reflects the need to control one's attention in the face of conflicting information.

Incongruency costs were calculated as accuracy differences when making congruent judgments versus making incongruent judgments. Congruent trials (*M* = .99, *SD* = .02) were typically responded to with higher accuracy than incongruent trials (*M* = .93, *SD* = .09), $F(1, 107) = 55.52$, *MSE* = .004, $p < .001$. This accuracy cost also demonstrated a marginal relationship with the antisaccade task, $r(108) = -.16$, $p = .10$, such that higher antisaccade accuracy was associated with smaller incongruency costs.

2. **Descriptive Statistics for Diffuse Attention Measures**

Number of Solutions on Remote Associates Task. All participants' data were included for the remote associates task. Performance was comparable to prior studies using these materials (Cushen, Jarosz, Aiello, & Wiley, 2010) Number of solutions correlated both with measures of focused attention and with performance on the anagram tasks.

Number of Solutions on Hinted and Non-hinted Anagrams. All participants' data were included for the anagram tasks. An effect was seen for the hints embedded in the reading-with-distraction task. The number of solutions was greater for hinted anagrams (*M* = .60, *SD* = .18) than for unhinted anagrams (*M* = .53, *SD* = .20), $F(1, 118) = 13.22$, *MSE* = .02, $p < .001$. For

the reading with distraction task, 81 participants received distractor words from Set A, while 39 received words from Set B. In the anagram task, no differences were seen in the average solution rates of A-hinted words versus B-hinted words across groups, $F(1, 118) = 2.65$, $MSE = .02$, *ns*. However, there was a significant interaction between word hint set and Reading with Distraction condition, $F(1, 118) = 16.34$, $MSE = .02$, $p < .001$, such that participants who received Set A in the Reading with Distraction task solved significantly more A-hinted anagrams ($M = .60$, $SD = .18$) than B-hinted anagrams ($M = .55$, $SD = .20$), $t(81) = 2.01$, $p = .05$. Participants who received Reading with Distraction Set B, however, solved significantly more B-hinted anagrams ($M = .60$, $SD = .18$) than A-hinted anagrams ($M = .49$, $SD = .19$), $t(39) = -3.91$, $p < .001$. These results demonstrate that the improvements seen in the hinted condition were specific to those items for which participants had been exposed to the solution words.

Overall number of solutions on the anagram tasks was correlated with performance on the Remote Associates task. A measure of the ability to benefit from embedded hints, calculated by subtracting the mean performance on non-hinted anagrams from performance on hinted anagrams, did not significantly relate to the other measures of diffuse attention.

3. **Descriptive Statistics for Flexibility Measures**

Navon Task-Switching Measures. As noted above, 11 participants were excluded from Navon analyses due to low accuracy and 1 due to a computer error. Before computing switching and mixing costs, data from the first 2 pure blocks and the first 16 mixed trials (for equivalence) were excluded to eliminate noise from learning the tasks. Additionally, the data from the first trial on each pure block was excluded as they represented odd "switch" trials within the pure blocks. Similarly, trials in the matched position during the mixed block were excluded for equivalence. All remaining reaction times were computed for correct trials and trimmed by

replacing outliers with values ±2 SDs from the participant's mean for the particular judgment type being replaced.

Both mixing costs and switch costs were observed in the Navon task. Evidence was seen for mixing costs, as trials during the mixed block (M = 1172.42, SD = 363.80) took significantly longer than trials during the pure blocks (M = 601.48, SD = 134.75), $F(1, 107) = 333.90$, MSE = 52719.44, $p < .001$. Evidence was also seen for switch costs, as trials requiring a switch from the previous judgment type (M = 1542.68, SD = 397.74) took significantly longer than those requiring no-switch (M = 1178.82, SD = 363.36), $F(1,107) = 152.92$, MSE = 48411.68, $p < .001$.

Neither the mixing costs nor the switch costs in this paradigm correlated with those in the visual search paradigm. The only significant correlation observed was a *negative* relation between mixing and switching within this task. This was an unexpected result, as these costs were anticipated to be additive. Instead, the costs appeared offsetting, with participants either incurring mixing costs, or switching costs, but not both.

Visual Search Task-Switching. Because the primary measures of interest from the visual search tasks were reaction times, participants were excluded from analyses if their overall judgment accuracy in the task was below 80%. As such, 3 participants were excluded from Visual Search analyses, due to low overall accuracy. After excluding these individuals, average accuracy was .91 (SD = .10). One individual was also excluded due to a computer error. Data trimming was completed in the same way as in the Navon task. Results were consistent with expectations regarding the Visual Search task: A repeated measures ANOVA on pure-block reaction times found that conjunctive search trials (M = 1848.34, SD = 629.21) took significantly longer to complete than disjunctive search trials (M = 1202.27, SD = 304.67), $F(1,114) = 423.70$, MSE = 266642.58, $p < .001$. Additionally, trials in which a target was not present (M = 1620.92,

SD = 566.12) took significantly longer to respond to than did trials in which a target was present (*M* = 1070.95, *SD* = 248.47), *F*(1, 114) = 235.46, *MSE* = 156965.94, $p < .001$. Further, there was a significant interaction, *F*(1, 114) = 126.09, *MSE* = 82611.28, $p < .001$, such that the target absent-present difference was smaller for disjunctive trials (*M* = 269.70, *SD* = 248.89) than for conjunctive trials (*M* = 867.86, *SD* = 652.35).

Evidence was seen for switch costs, as trials requiring a switch from the previous judgment type (*M* = 1435.84, *SD* = 393.18) took significantly longer than those requiring no-switch (*M* = 1285.92, *SD* = 391.39), *F*(1,115) = 71.29, *MSE* = 15219.52, $p < .001$. However, no evidence of a mixing cost was found, with trials during the mixed block (*M* = 1285.92, *SD* = 391.39) taking the same amount of time to complete as trials during the pure blocks (*M* = 1299.74, *SD* = 368.04), *F*(1,115) = .43, *MSE* = 25602.24, *ns*. As noted above, the mixing and switch costs in this paradigm did not relate to those in the Navon paradigm. However, the same negative relation was observed between the mixing and switching costs within the paradigm. Again this relationship was not anticipated, as these costs were expected to be additive.

Viability of a Factor for Flexibility. Neither the mixing nor the switching costs from the Visual Search task were correlated with those same costs from the Navon task, suggesting a lack of consistency across these tasks. The lack of a relationship between these factors reflects poorly on the validity of considering both as measures of task-switching ability. Consistent with the use of pure Navon RTs as a measure of focused attention, measures derived from the Navon task seemed more appropriately measures of focused attention, similar to a flanker task. Indeed, it had previously been used for this purpose by Bialystok (2010). Further, participants' performance on the Visual Search task failed to reflect any mixing costs and both the mixing and switching cost measures demonstrated low reliability.

Additionally compounding the difficulty with deriving a single factor of task-switching ability from these tasks was the result that mixing and switching costs were negatively related to one another in both tasks. This relationship was unexpected, as both costs were expected to be independent and additive. Instead, this negative relationships suggest a strategic trade-off in which participants either kept both sets active (incurring mixing costs but less switch costs) or failed to keep both sets active (incurring switching costs but less mixing costs).
The tradeoff in mixing and switching costs complicates the interpretation of these costs.

Given the unreliability and potential invalidity of the mixing and switching cost measures obtained from both the Navon and Visual Search tasks, these measures were not included in the overall factor analysis, and a flexibility factor was not derived. This difficulty is addressed further in the discussion.

4. **Deriving Attention Factors**

Prior to deriving any factors, corrections were applied to several measures to decrease skew. An arcsine transform was applied to the negatively-skewed antisaccade scores. For both the reading with distraction errors and the Navon incongruency accuracy costs, constants were added (1.00 and 1.10, respectively) to ensure all values were positive, and values were log (ln) transformed to correct for positive skew. (A more complicated Box-Cox transformation was also attempted to further reduce the skewedness of the Navon incongruency costs. Results of the factor analyses were unchanged by this more complicated analysis, so results from the simpler log transform are included and discussed.) Descriptive statistics for these transformed variables are reported beneath the untransformed variables in Table 3.

Exploratory Factor Analysis. An exploratory factor analysis using principal axis factoring was used to investigate the relationships between the attention measures collected in

this study. Factors were rotated using direct oblimin rotation to allow them to correlate with one another. This analysis resulted in three factors with eigenvalues greater than 1, accounting for 35% of the total variance. These factors are shown under the "Exploratory Factor Analysis" heading in Table 5. To summarize, these factors correspond to 1) a focused attention factor, 2) an incongruency cost factor, and 3) a diffuse attention factor. These results highlight two points. First, they support the theoretical distinction of the diffuse measures from the focused attention measures. Second, they suggest that the Navon incongruency cost measure does not integrate well with the other measures of focused attention. Because of this latter finding, the incongruency cost measure is not included in the computation of composite scores.

Creation of Composite Scores. For the purpose of the predictive analyses, two composite scores were derived. Principle axis factoring was used to derive a common "focus" factor from the focus attention measures (antisaccade accuracy, working memory composite, reading with distraction errors, and average Navon RT). This factor explained 26.96% of the shared variance in the focused attention measures and factor loadings can be seen under the "Composite Scores Factor Analyses" heading in Table 5. A separate principle axis factoring was used to derive a common "diffuse" factor from the diffuse attention measures (RAT accuracy, anagram accuracy, and benefit from hints). This factor accounted for 25.57% of the shared variance and factor loadings can also be seen in Table 5. The focused and diffuse attention factors were significantly correlated with one another, $r\,(98) = .47$, $p < .001$.

The choice to use these composite scores was motivated by several reasons. First, the division of these variables was predicted *a priori* by theories regarding performance on these measures. Second, that division was supported by the exploratory factor analysis reported above. Finally, composite scores were used, as opposed to the factors derived from the exploratory

factor analysis, due to the moderate number of subjects involved in this study. The number of subjects per variable in the factor analysis (12.5) does not reach the recommended 20 subjects per variable (Hogarty, Hinzes, Kromrey, Ferron, & Mumford, 2005) for establishing confidence in the factors derived from an exploratory factor analysis. As such, the composite measures are used in all predictive analyses.

5. **Prediction of Spontaneous Transfer**

The primary dependent variable of interest was whether a participant would spontaneously generate the convergence solution suggested in "The Lightbulb" when solving the Ray Problem. Sixty-two participants (52%) spontaneously generated the convergence solution during this problem-solving period. Table 6 describes the correlations between the relevant individual difference measures and factors and analogical transfer performance.

As shown in Table 6, both the focused attention and the diffuse attention factors were significantly correlated to spontaneous generation of the convergence solution. However, presence or absence of the convergence solution is a dichotomous variable and correlation coefficients are not ideal for quantifying the way in which it relates to predictor variables. Instead, binary logistic regression was used to assess whether a unique contribution of these factors could be identified for spontaneous generation of the convergence solution. The results of this regression analysis are shown in Table 7.

To summarize, when entered first, the focused attention factor significantly predicted spontaneous analogical transfer. When entered in the second block, the diffuse attention factor significantly increased the fit of the model and was itself a significant predictor of spontaneous transfer. The focused attention factor also remained as a significant predictor, indicating that both factors contributed uniquely to predicting the likelihood of spontaneous transfer. These

results suggest that, as predicted, both focused attention and diffuse attention are important to spontaneous analogical transfer.

6. **Prediction of Prompted Retrieval and Use**

Successful spontaneous transfer requires participants to notice the relevance of previously experienced information, to have access to the previously experienced information, and make use of that information by drawing analogical mappings between the source and target. As such, identifying the factors that predict spontaneous transfer describes the contribution of those factors collapsing across both retrieval and mapping. To more specifically investigate the contribution of these factors in analogical mapping, several outcomes were examined that did not depend on an individual's ability to notice the relation with the source story.

On the final questionnaire, participants were prompted to generate the solution to the Ray Problem suggested by "The Lightbulb" story. All participants provided a response to this question and it serves as a measure of whether a participant was capable of retrieving and making use of the convergence solution from "The Lightbulb" when prompted, regardless of their performance during the problem-solving task.

As seen in Table 6, both the focused and diffuse attention factors related significantly to the ability to generate the convergence solution when prompted on the final questionnaire. The results of a binary logistic regression are shown in Table 8. To summarize, a model including the focused attention factor significantly predicted generation of the convergence solution when prompted. However, once the diffuse attention factor was entered into the model, the resultant model was significantly better at predicting participants' generation of the convergence solution when prompted. Prediction of another measure of prompted retrieval, hinted solutions, is presented in Appendix H.

TABLE III
DESCRIPTIVE STATISTICS ON SIMPLE AND TRANSFORMED INDIVIDUAL DIFFERENCE MEASURES

Measure (N)	Mean	SD	Range	Skew	Kurtosis
Focused Attention					
Antisaccade Accuracy (120)	.81	.16	.28 – 1.00	-1.42	1.74
Antisacc Acc (Arcsine)	.99	.27	.28 – 1.57	-.38	.30
WMC Composite (114)	.55	.15	.17-.88	.21	-.35
Symmetry Span (115)	.44	.19	.03 - .87	.27	-.42
Operation Span (119)	.66	.16	.28 – 1.00	-.01	-.66
Read w/ Dist Errors (118)	14.09	27.03	0 - 199	4.81	26.24
Read w/ Dist Errors (LN)	2.11	.99	.00 – 5.30	.59	1.15
Average Navon RT (108)	970.56 msec	218.30	479.29 – 1678.00	.68	.69
Navon Incong Acc Cost (108)	.06	.09	-.10 - .45	1.97	5.36
Nav Incong Acc Cost (LN)	.15	.07	.00 - .44	1.64	3.81
Diffuse Attention					
RAT Solutions (120)	.41	.17	.00 - .84	-.28	-.33
Anagram Solutions (120)	.57	.16	.10 - .85	-.36	-.24
Benefit from Hints (120)	.07	.20	-.50 - .60	-.19	.24
Task-Switching					
Navon Mix Cost (108)	542.27 msec	324.81	-126.22 – 1759.72	.94	2.01
Navon Switch Cost (108)	370.26 msec	311.16	-635.95 – 1425.26	.27	1.61
Vis Search Mix Cost (117)	13.70 msec	225.31	-884.88 – 1288.05	1.31	10.51
Vis Search Switch Cost (117)	148.64 msec	174.27	-457.55 – 717.03	-.17	2.32
Total Reading w/ Dist Time (121)	179634.83 msec	41213.09	–102340.00 – 294472.00	.68	.11

TABLE IV
CORRELATIONS BETWEEN INDIVIDUAL DIFERENCE MEASURES

Individual Difference Measure	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Antisaccade Acc	-	.29**	-.20*	-.30*	-.16†	.27**	.29**	.08	-.19†	-.02	.14	-.07	-.19*
2. WMC Composite	114	-	-.26**	-.20*	-.08	.31**	.21*	-.07	-.08	-.10	.04	.01	-.13
3. Read w/ Dist Errs	118	112	-	.14	.10	-.22*	-.18†	-.00	.12	.10	-.17†	.11	.27**
4. Average Navon RT	108	102	106	-	.13	-.16	-.20*	.01	.66**	.07	.01	.16	.32**
5. Navon Incong Cost (Acc)	108	102	106	108	-	-.29**	.02	.02	.08	-.18	.04	.23*	.25**
6. RAT Solutions	120	114	118	108	108	-	.36**	-.14	.04	.05	.00	-.09	-.36**
7. Anagram Solutions	120	114	118	108	108	120	-	-.11	-.03	.03	-.02	-.08	-.26**
8. Benefit from Hints	120	114	118	108	108	120	120	-	-.03	-.07	.22*	-.05	.11
9. Navon Mix Cost (RT)	108	102	106	108	108	108	108	108	-	-.37**	-.02	.04	.11
10. Navon Switch Cost (RT)	108	102	106	108	108	108	108	108	108	-	-.10	.12	.02
11. Vis Search Mix Cost (RT)	117	111	115	105	105	117	117	117	105	105	-	-.41**	-.04
12. Vis Search Switch Cost (RT)	117	111	115	105	105	117	117	117	105	105	117	-	.15
13. Total Read w/ Dist Time (RT)	120	114	118	108	108	120	120	120	108	108	117	117	-

Note. Values above diagonal represent correlation coefficients. Values below diagonal represent N for each correlation.

** $p < .01$, * $p < .05$, † $p < .1$

TABLE V

FACTOR LOADINGS ON OVERALL FACTOR ANALYSIS AND ON SEPARATE FOCUSED AND DIFFUSE FACTORS

	Exploratory Factor Analysis (N = 100)			**Composite Scores Factor Analyses**	
Measure	**Factor 1**	**Factor 2**	**Factor 3**	**Focused (N = 100)**	**Diffuse (N = 120)**
Antisaccade (Arcsine)	.63	-.20	-.05	.54	
Composite WMC	.44	-.16	-.23	.51	
Read w/ Dist Errors (LN)	-.57	.29	.26	-.57	
Average Navon RT	-.42	.17	.01	-.44	
Navon Incong Acc Cost (LN)	-.25	.71	.01		
RAT Accuracy	.48	-.41	-.58		.66
Anagram Accuracy	.55	.11	-.48		.54
Hinted Anagram Acc Diff	-.05	.04	.36		-.20

TABLE VI

CORRELATIONS BETWEEN INDIVIDUAL DIFFERENCE FACTORS, SIMPLE MEASURES, AND MEASURES OF SPONTANEOUS TRANSFER, PROMPTED RETRIEVAL AND MAPPING

Individual Difference Measure	**Spontaneous Convergence**	**Prompted Retrieval**	**Lightbulb Helpfulness**
Focused Attention Factor	**.40****	**.31****	**.41****
Antisaccade Acc(Arcsine)	.30**	.18*	.20*
WMC Combined Score	.35**	.22*	.35**
Read w/ Dist Errors (LN)	-.21*	-.26**	-.23*
Average Navon RT	-.09	.04	.01
Diffuse Attention Factor	**.39****	**.34****	**.31****
RAT Accuracy	.36**	.35**	.27**
Anagram Accuracy	.27**	.21*	.23**
Hinted Anagram Acc Diff	-.12	.06	-.11
Total Reading w/ Dist Time	**-.19***	**-.15**†	**-.27****

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

TABLE VII

LOGISTIC REGRESSION PREDICTING SPONTANEOUS TRANSFER BY INDIVIDUAL DIFFERENCE FACTORS

	B	***S.E.***	***Wald***	R^2	X^2	ΔX^2
Block 1				.21	17.41**	
Focused	1.28	.35	13.11**			
Block 2				.26	21.88**	4.47**
Focused	1.00	.37	7.22**			
Diffuse	.74	.36	.418*			

Note: ** $p < .01$, *$p < .05$ for $N = 100$.

TABLE VIII
LOGISTIC REGRESSION PREDICTING GENERATION OF THE CONVERGENCE SOLUTION DURING PROMPTED RETRIEVAL BY INDIVIDUAL DIFFERENCE FACTORS

	B	***S.E.***	***Wald***	R^2	X^2	ΔX^2
Block 1				.15	10.36**	
Focused	1.08	.37	8.71*			
Block 2				.24	17.15**	6.80*
Focused	.77	.40	3.79*			
Diffuse	1.04	.42	6.13*			

Note: ** $p < .01$, *$p < .05$for $N = 100$.

7. **Prediction of Mapping**

Individuals capable of drawing the connections between the solution suggested by "The Lightbulb" and the problem posed by the Ray Problem should rate the story as having been more helpful in solving. As seen in Table 6, both the focused and diffuse attention factors related to rated helpfulness of the story, with higher values in either factor relating to higher ratings of helpfulness.

Linear regression was used to predict participants' ratings of story helpfulness based on the individual difference factors. Table 9 shows the results of this regression. When entered into the first block in the model, the focused attention factor significantly predicted participants' helpfulness ratings. When the diffuse attention factor was entered into the model in the second block, it did not serve as a significant predictor of how helpful a participant rated “The Lightbulb” story, and its inclusion did not improve the overall fit of the model. These results suggest that the primary determinant of the helpfulness ratings was the focused attention factor.

TABLE IX
LINEAR REGRESSION PREDICTING RATED HELPFULNESS OF "THE LIGHTBULB" BY INDIVIDUAL DIFFERENCE FACTORS

	B	***S.E.***	**B**	***T***	R^2	$F(R^2)$	ΔR^2	$F(\Delta R^2)$
Block 1					.16	19.33**		
Focused	1.23	.28	.41	4.40**				
Block 2					..17	11.10**	.02	2.56
Focused	.1.00	.31	.33	3.18**				
Diffuse	.54	.34	.17	1.60				

Note: ** $p < .01$, *$p < .05$ for $N = 100$.

8. **Representation Quality**

One final point of analysis was the relationship between the quality of a participant's representation of "The Lightbulb" story, transfer, and individual differences. To examine these relationships, it was first necessary to code the summaries to assess the quality of solvers representations as in Study 2. Two independent coders identified instances of each concept in participants' summaries. Inter-rater reliability was .88, with disagreements being resolved by a third rater. From these summaries, 3 measures of representation quality were derived on the basis of prior research and the results from Study 2: inclusion of the problem-solving constraint (SC2), completeness of the convergence schema, and completeness of total story summary. Correlations between these three representational quality measures, spontaneous transfer, prompted retrieval and mapping measures are summarized in Table 10.

TABLE X
CORRELATIONS BETWEEN REPRESENTATION, ANALOGY MEASURES, AND INDIVIDUAL DIFFERENCE MEASURES

Analogy Measures	**SC 2 (Constraint)**	**Convergence Schema**	**Total Summary**
Spontaneous Transfer	.39**	..12	.29**
Prompted Retrieval	.29**	.13	.32**
Lightbulb Helpfulness	.34**	.17†	.37**
Individual Difference Measure			
Focused Attention	.10	.14	.23*
Diffused Attention	.07	.19*	.22*
Reading w/ Distraction Time	-.14	-.14	-.21*

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

As in Study 2, participants who included the concept, “A high-intensity ultrasound wave would also break the glass,” (SC2; a constraint on solution in the story) were significantly more likely to spontaneously generate the convergence solution, $x^2(1, N = 120) = 18.26$, $p < .001$. They were also significantly more likely to generate the convergence solution in response to the questionnaire prompt to describe the solution suggested by "The Lightbulb," $x^2(1, N = 120) = 9.83$, $p = .002$, and also rated the story as more helpful, $F(1, 118) = 14.89$, $MSE = 4.55$, $p < .001$. While the inclusion of the constraint statement was significantly predictive of the likelihood of spontaneously generating the convergence solution, no factor was found to predict the inclusion of the constraint statement in participants’ story summaries.

The overall completeness of a participant's summary (out of 8 concepts) also significantly predicted measures of both spontaneous transfer, $x^2(1, N = 120) = 10.48$, $p = .001$, and the rated

helpfulness of the story, r (118) = .37, $p < .001$. As in Study 2, the completeness of the convergence schema did not predict any of the transfer or mapping outcomes. As shown in the bottom half of Table 10, both the focused and diffuse factors related to the completeness of an individual's story summary (out of 8). Further, the diffuse factor also related to the completeness of the convergence schema (out of 3). This finding suggests that some aspect of the relationship between the individual difference factors and spontaneous transfer may be explained by their association with an individual's story representation. Construction of a more complete representation could serve to provide more cues to facilitate the retrieval of "The Lightbulb" story during Ray Problem solving. Amore detailed analysis of participants' story representations and the relationship between representational elements and spontaneous transfer is included in Appendix I.

Representation, Attention, and Spontaneous Transfer. It is possible that the relationship between the attention factors and spontaneous transfer could be mediated by the quality of the representation of the source story. As such, two hierarchical binary logistic regression analyses was conducted to assess whether the attention factors and the representation measure each contribute uniquely to predicting spontaneous transfer. Both of these analyses predicted spontaneous generation of the convergence solution as a function of the completeness of an individual's story summary, their focused attention score, and their diffuse attention score, but differed in terms of the order variables were entered into the analysis.

The first of these analyses examined whether the focused and diffuse attention factors predicted variance after controlling for representation quality (by entering participant's total summary scores into the model in the first block). This analysis thus addresses whether the impact of the attention factors can be explained entirely by their impact on the story

representation. Additional variance explained after controlling for story representation would indicate that the influence of the attention factors on spontaneous transfer cannot be explained solely by their impact on story representation. The results of this regression are shown in Table 11.

TABLE XI
LOGISTIC REGRESSION PREDICTING SPONTANEOUS GENERATION OF THE CONVERGENCE SOLUTION BASED ON THE FOCUSED AND DIFFUSE ATTENTION FACTORS CONTROLLING FOR TOTAL STORY SUMMARY

	B	***S.E.***	***Wald***	R^2	X^2	ΔX^2
Block 1				.13	10.25**	
Total Summary	2.76	.92	9.05**			
Block 2				.29	24.01**	13.75**
Total Summary	2.44	.99	6.07*			
Focused	1.20	.37	10.87**			
Block 3				.33	27.99	3.98*
Total Summary	2.41	1.02	5.59*			
Focused	.95	.39	6.02*			
Diffuse	.71	.37	3.73*			

Note: ** $p < .01$, *$p < .05$ for $N = 100$.

To summarize, the completeness of an individual's story summary was a significant predictor of spontaneous transfer in the first block of the regression. The addition of the focused attention factor and the diffuse attention factor in the second and third blocks, respectively, both increased the predictiveness of the model, with both factors remaining significant predictors in

the final block. A similar analysis examining the role of reading ability on both representation and on the relationship between representation, attentional factors, and spontaneous transfer are presented in Appendix J.

A second analysis assessed whether the impact of representation quality would explain additional variance after controlling for the attention factors by first entering the attention factors into the model and then seeing whether adding the representation measure to the model significantly improved the model. Improved model fit due to the representation measure after controlling for the attention factors would suggest an impact of source representation on transfer in addition to that of the attention factors. This analysis is shown in Table 12. To summarize, even after controlling for the attention factors in the first block of the model, the addition of the story representation measure significantly improved the fit of the model. This suggests a unique role of representation quality in predicting spontaneous transfer.

Representation Summary. Both the inclusion of the constraint statement and a higher proportion of story concepts in the summary were found to predict analogical transfer and mapping outcomes. Interestingly, while both the focused and diffuse attention factors significantly related to the completeness of the total story summary, neither factor predicted the inclusion of the constraint statement. Further, there was evidence that both representation quality and the focused attention factors predicted unique variance in spontaneous transfer of the convergence solution. After controlling for the completeness of an individual's story representation, both the diffuse and focused attention factors still contributed to predicting spontaneous transfer; and, after controlling for the attention factors, the completeness of an individual's story summary still predicted unique variance as well. These results suggest that

both the source representation and individual differences in attentional abilities may be needed for spontaneous transfer to occur.

TABLE XII
LOGISTIC REGRESSION PREDICTING SPONTANEOUS GENERATION OF THE CONVERGENCE SOLUTION BASED ON TOTAL STORY SUMMARY CONTROLLING FOR THE FOCUSED AND DIFFUSE ATTENTION FACTORS

	B	***S.E.***	***Wald***	R^2	X^2	ΔX^2
Block 1				.26	21.88**	
Focused	1.00	.37	7.22**			
Diffuse	.74	.36	4.18			
Block 2				.33	27.99	6.10*
Focused	.95	.39	6.02*			
Diffuse	.71	.37	3.73*			
Total Summary	2.41	1.02	5.59*			

Note: ** $p < .01$, *$p < .05$ for $N = 100$.

9. **General Summary**

Both the focused and diffuse attention factors were found to predict variance in the transfer and mapping measures. In spontaneous transfer, both factors predicted the likelihood of spontaneous generation of the convergence solution. Further, both factors were found to relate when the requirement for spontaneously noticing the relationship between the source and target was removed (prompted retrieval) and both factors predicted unique variance in the rated helpfulness of "The Lightbulb." While both the focused and diffuse attention factors were shown

to relate to measures of representation, both the attention and representation measures predicted unique variance in participants' spontaneous generation of the convergence solution.

C. Discussion

1. Focused Attention and Analogical Transfer.

A consistent role was seen for focused attention in predicting analogical transfer success. The focused attention factor contributed uniquely to predicting the likelihood of an individual spontaneously generating the convergence solution, in generating that solution during prompted retrieval, and in assessing the mapping quality between the source and target.

Two possible mechanisms were proposed that could explain why analogical transfer might be facilitated by focused attention. One of these mechanisms was that greater focused attention may relate to an improved quality of an individual's source representation. This prediction was based on research suggesting working memory capacity to relate to both text comprehension (Daneman & Carpenter, 1980; Friedman & Miyake, 2000; Singer & Ritchot, 1996; Turner & Engle, 1989) and representational quality in mathematical problem solving (Andersson, 2007). Indeed, a relationship was identified between the focused attention factor and the completeness of an individual's story summary. However, controlling for that summary did not eliminate the role of focused attention in transfer. This result suggests that, while there does seem to be a relationship between focused attention and representation quality, that relationship does not fully explain the role of focused attention in analogical transfer. The second proposed mechanism was that greater focused attention facilitates analogical mapping ability. Prior research (Chuderska & Chuderski, 2009; Morrison et al., 2004; Richland et al., 2006, 2010; Viskontas, Morrison, Holyoak, Hummel, & Knowlton, 2004; Waltz, Lau, Grewal, & Holyoak, 2000) had emphasized the relationship between focused attention and the ability to manage

increasing levels of analogical complexity and avoid negative consequences from distracting information in identifying appropriable object mappings. The results of this study are consistent with this explanatory mechanism. A role for the focused attention factor was identified in all measures that incorporated the need to draw a mapping between source and target.

Finally, it was suggested that focused attention might actually harm the ability to notice distant analogies, as it may relate to the inhibition of extraneous information during problem solving and prevent the previously presented source from coming to mind. However, there was no evidence of focused attention preventing spontaneous transfer.

These results reinforce the findings from prior research as to the importance of focused attention in facilitating analogical mapping. Even when using a more holistic paradigm that includes representation, noticing, and retrieval, the role that focused attention plays in facilitating transfer is still consistently evident.

2. **Diffuse Attention and Analogical Transfer**

This research also presents the novel finding that additional variance in analogical transfer success can be explained by including measures of diffuse attention. It was initially proposed that diffuse attention should facilitate analogical transfer by increasing the rate at which participants notice the relevance of the prior source to problem solving. Indeed, when examining spontaneous transfer, the diffuse attention factor improved the prediction of transfer, after accounting for focused attention. However, if diffuse attention were only playing a role in whether participants initially notice the relevance of the source, then one would not expect to see a role for it in prompted retrieval for which spontaneous noticing is unnecessary. Yet, in this additional measure, the diffuse attention factor also improved the model after controlling for the focused attention factor.

One possible explanation for this effect may lie in the association between diffuse attention and representation quality. A significant relationship was identified between the diffuse attention factor and the completeness of an individual's story summary. This relationship may reflect a greater likelihood for individuals with diffuse attention to be less restrictive and more inclusive in their story summaries. This inclusiveness may provide these individuals with a more robust representation of the source and with a larger number of cues by which they can retrieve that source when later prompted.

Another explanation may be that responses to the prompted retrieval question are naturally confounded with successful spontaneous transfer such that spontaneously transferring between the source and target (which is predicted by diffuse attention) is highly correlated with successfully retrieving the convergence solution when prompted, $r\,(118) = .53$, $p < .001$. As such, this effect may reflect a carryover from the spontaneous transfer effect.

The above explanation would be consistent with the idea that diffuse attention is relating both to the inclusiveness of an individual's representation and an increased likelihood of considering/noticing the relevance of the source story, and that this initial noticing has carry-over effects to later reporting of the convergence solution. However, there are also several alternate interpretations of this factor that may offer different explanations for the pattern of results identified. The following section will address these alternate interpretations.

Alternate Interpretations of the Diffuse Attention Factor. While the common variance derived from the RAT and anagram tasks is defined as "diffuse attention" in these analyses, there are several alternate explanations that could influence how these results are interpreted. The first of these alternate explanations is that the diffuse factor actually reflects some metric of focused attention. Indeed, the diffuse and focused attention factors were found to be significantly

correlated (r = .47). This significant relationship is consistent with the fact that both the RAT and the anagram tasks have been identified as solvable either via focused, serial search processes, or via diffuse, parallel associative processes. This dual-nature of solution is difficult to avoid, as most idea-generation (e.g. brainstorming, Goldenberg & Wiley, 2011) or divergent thinking measures (e.g. alternate uses, Goff & Torrance, 2002) can be subjected to the same criticism.

This difficulty was addressed via the method of analysis employed in this study. In all regression analyses, the focused attention factor was entered first into the regression model. This factor, including measures of inhibition and working memory capacity, is less ambiguous in its representation of controlled attention. Therefore, when the diffuse attention factor is entered into the regression equation *after* this focused attention factor, then any additional improvement should relate to the unique contribution provided by the diffuse attention factor. It is my opinion that the unique contribution associated with these tasks (after controlling for focused attention) represents the success on this task attributable to the diffuse, associative problem-solving processes that have also been identified as contributing to performance on these tasks.

A second possible interpretation of the diffuse attention factor is that it actually represents some measure of verbal ability, as both the Remote Associates and anagram tasks are verbal in nature. Moreover, when controlling for reading ability (see Appendix J), the relationship between the diffuse attention factor and representation quality was diminished. This interpretation may also explain why the diffuse attention factor was found to relate both to spontaneous transfer as well as hinted retrieval, since verbal ability may relate to the capacity to accurately depict the convergence solution in both of these cases. However, if verbal ability were entirely responsible for the influence of the diffuse attention factor, then one might expect the relationship between the factor and spontaneous transfer to be eliminated after controlling for

reading ability. After conducting this analysis (Appendix J), little evidence was seen for reading ability to mediate the relationship between the diffuse attention factor and spontaneous transfer.

Unfortunately, this analysis does not entirely rule out this alternate interpretation of the diffuse attention factor, as a measure of reading ability is not identical to a measure of verbal ability. A stronger investigation would involve the use of non-verbal measures of diffuse attention and divergent thinking, such as the figural version of the Torrance Test of Creativity (Goff & Torrance, 2002). If a diffuse attention factor including divergent thinking measures derived from these tasks demonstrated the same relationship with spontaneous transfer as identified in this study, then it would provide converging evidence for the role of diffuse attention as opposed to verbal ability.

A further possible interpretation of these factors is that the focused attention factor represents fluid intelligence (gF), or general intellectual ability, while the diffuse attention factor represents crystalized intelligence (gC), or knowledge (Cattell, 1963). This critique is consistent with the interpretation of the diffuse attention factor as a measure of verbal ability, since the knowledge in this case would be vocabulary knowledge. Like the verbal ability possibility, the gC critique cannot be directly addressed by this data. However, also like the verbal ability possibility, this critique can also be addressed in part by introducing non-verbal measures of diffuse attention and divergent thinking.

3. **Task Switching Measures**

While another goal of this study was to include in these analyses measures of attentional flexibility, this goal could not be realized for a number of reasons. As mentioned in the descriptive analyses of both the Navon and the Visual Search task-switching tasks, neither the mixing costs nor the switching costs of these tasks correlated with those same costs calculated

for the other task. Reaction times on the Visual Search task failed to demonstrate mixing costs entirely. (This lack of a cost may be due to the fact that the mixed block in this task did not involve having to maintain multiple goals concurrently, as the goal in this task was *always* to identify the presence or absence of a blue X.) It was initially suggested that these tasks may represent different switching abilities and thus may not relate *strongly* to one another. However, the complete lack of a relationship was problematic for the goal of deriving a factor explaining common variance across both tasks. This lack of association may be explained in part by the inconsistent reliability measures obtained from these tasks; several odd-even calculations derived from this task resulted in weak levels of reliability.

A further difficulty was that, for both tasks, mixing costs were negatively correlated to switching costs. That is, it seemed as if individuals were either incurring mixing costs or switching costs, but not both. As discussed previously, this suggests that these costs were being influenced by strategic choices to either emphasize the maintenance of both task sets (thereby incurring mixing costs, but not switching costs) or ignoring the maintenance of both task sets (thereby incurring switching costs, but no mixing costs). This tradeoff was unexpected, as these costs were anticipated to be independent and additive. Further, the relationship between these costs made it impossible to accurately measure either cost independently. Given the poor reliability and the inability to distinguish between whether aspects of attention or strategy were contributing to those costs, the decision was made not to pursue an analysis of the task-switching measures.

Given that a role for both focused and diffuse attention was identified in this study, the influence of attention flexibility does merit further investigation. It still remains plausible that the ability of an individual to change the focus of their attention may allow them to experience the

benefits of both focused and diffuse attention while problem solving. However, in light of the deficiencies in the current tasks, a different strategy may be more beneficial to addressing this question. For example, it may be necessary to make use of measures of attentional flexibility that do not rely on the calculation of difference scores. Several candidate tasks may be the ambiguous figure and figure-ground reversal tasks (Bialystok & Shapero, 2005). These tasks attempt to quantify the difficulty an individual experiences in interpreting an image in multiple ways, with less difficulty being associated with greater flexibility. In this way, it may be possible to obtain reliable measures that will allow for assessing the influence of attentional flexibility on transfer.

4. **Representation and Analogical Transfer**

An exciting result of this research has been to identify the elements of an individual's story representation that relate to spontaneous transfer. Firstly, the completeness of an individual's story summary was a significant predictor of spontaneous transfer performance. This demonstrates that the quality of a participant's representation of a single source, as opposed to the quality of their schema extracted across multiple stories, is facilitating spontaneous transfer.

Second, the quality of the convergence schema, commonly assessed and considered critical in studies of analogical transfer, did not predict spontaneous transfer in either study. An explanation for failing to identify a role of the convergence schema in these results may lay in the fact that the importance of the convergence schema has primarily been identified in paradigms requiring individuals to compare two different sources (e.g. Catrambone & Holyoak, 1989; Gick & Holyoak, 1983). A participant's generation of the convergence schema in these paradigms involves a mapping across two source stories. Thus, this finding may say more about the relationship between an individual's ability to construct a mapping between two sources and

how *that* ability relates to their ability to map between source and target than it does about the importance of completeness of the convergence schema itself in promoting spontaneous transfer.

Finally, the inclusion of the constraint on problem solving (A high-intensity ultrasound wave would also break the glass, SC2) in the Lightbulb story summary was consistently related to spontaneous transfer. No individual differences were found that predicted the inclusion of this constraint, suggesting that the inclusion of this constraint in one's source representation is a starting point in facilitating spontaneous transfer. It seems likely that the encoding of this constraint is facilitative in that an analogous constraint is clearly stated in the Ray Problem. ("Unfortunately, at this [ray] intensity the healthy tissue that the rays pass through on the way to the tumor will also be destroyed.") As such, the identification and alignment of this constraint across source and target may serve as a starting point for developing the analogical mapping that will allow for the transfer of the convergence solution. The encoding of the convergence schema itself would not facilitate this noticing or initial alignment, as no analogous solution statements are present in the target problem.

Other research has demonstrated that the initial alignment of features is critical to successful transfer. Much of this research has focused on the role that superficial overlap between source and target plays in initial noticing (Holyoak & Koh, 1987) and in the detrimental effect that the superficial overlap can play in successful mapping (Blessing & Ross, 1996; Ross, 1989). The results of this study suggest that the existence of a salient relationship (the prospect of peripheral damage constraining an initial use of strong force) may also serve the same role. This possibility suggests several potential manipulations that should influence the likelihood of spontaneous transfer from a source that might serve as directions for future research.

5. Implications for "Far" Transfer

As noted in the introduction, the paradigm used in this study has been commonly used in laboratory research on analogical transfer. In this paradigm, "spontaneous" transfer is defined as a participant, without the aid of a hint, recognizing the relevance and making use of (transferring) information presented in a reading task for the purpose of solving a problem-solving task. These paradigms are often examining transfer within the same session (Catrambone & Holyoak, 1989; Gick & Holyoak, 1983; Holyoak & Koh, 1987) and with very little contextual difference between the source and the target. This type of "spontaneous transfer," however is different from the ideal of distant and creative transfer that researchers are ultimately trying to understand and facilitate.

Barnett and Ceci (2002) described a taxonomy of the ways in which transfer can be "distant," including not only content domain but also physical, temporal, functional, and social contexts. As an example, maximally distant transfer according to this taxonomy may be something akin to learning a piece of biological information, sitting in the library, during college, cramming for an exam, privately, and making use of that information on an engineering problem, in a work context, decades later, while troubleshooting, with a group of others. By contrast, the transfer in this study occurred across content domain (though with some superficial overlap), but did not differ in terms of physical, temporal, functional, or social contexts, as the materials were presented in the same room, within the same session, as parts of an experiment, and administered individually, respectively. However, this does not mean that the present results do not provide some understanding of the ways in which attention may facilitate this type of distant transfer.

Barnett and Ceci elaborated their taxonomy to help researchers to identify exactly what barriers to transfer were present in their paradigm. In the case of this research, the primary barrier to transfer is that the source and target used were different in terms of content domain. Additional research will be necessary to identify whether both focused and diffuse attention are critical to overcoming additional difficulties such as temporal distance or functional differences (e.g. sources presented in class versus targets encountered in real-world problem solving) between source and target. If, as suggested, diffuse attention is facilitating transfer by increasing the likelihood that an individual will *notice* the relevance of a prior experience, then one might expect the influence of that factor to increase as a function of the "distance" (or number of barriers to transfer) between source and target. Whether diffuse attention will facilitate the overcoming of all or just some of the barriers to transfer is an open question that can be addressed in future research by experimentally manipulating the distance of transfer along the lines described by Barnett and Ceci. Nevertheless, the present results contribute to the understanding of what factors facilitate spontaneous transfer by providing evidence for a role of both focused and diffuse attention when the primary barrier to transfer is a difference in content domain between source and target.

6. **Future Directions**

Representation Manipulation. As noted above, the representation of the constraint on problem solving in the source story was a strong predictor of spontaneous transfer. Further, results suggested its effects to be independent of the individual differences in attention, as no individual difference measure was seen to predict its inclusion in a participant's story summary. As such, it seems like it may be a prime target for manipulations that could increase or decrease the likelihood of spontaneous transfer from any particular source.

Given that "The Lightbulb" also demonstrates some superficial overlap with the Ray Problem, it is difficult to say whether it is the similarity of constraint relationship that is facilitating transfer or whether it is the similarity in the words and details used to describe the constraints in both stories. One way of assessing this would be to investigate whether the identification of the analogous constraint in a less superficially similar source will also show the same degree of facilitation. This can be done in two ways. The first is to assess the degree to which previously-used, superficially dissimilar sources (e.g. The General) facilitate the encoding of the peripheral damage constraint and whether the inclusion of this constraint in a story summary demonstrates the same strong relationship as identified with the Lightbulb story. If the representation of the constraint relationship is critical to facilitating transfer, then its inclusion in a story summary should relate to spontaneous transfer regardless of the degree of superficial overlap between source and target.

The second strategy would be to manipulate the Lightbulb story (or any source story) directly so as to emphasize, de-emphasize, or reduce the superficial similarity (to the Ray Problem) of that constraint in the story. For example, one could emphasize the constraint by providing extra details about why it was important to avoid breaking the lightbulb, one could de-emphasize the constraint by removing it entirely and simply noting that the lab assistant's initial solution strategy did not work, or one could reduce the superficial similarity by manipulating the terminology used to make it less similar to the Ray Problem (as in Holyoak & Koh, 1987). Both of these manipulations could help to further understand the reasons why inclusion of the problem-solving constraint in one's story summary is so predictive of spontaneous transfer.

Multiple Source Transfer. The relationships between individual differences and spontaneous transfer seen in this study were identified in a paradigm presenting only one story

and testing the impact of that one story on transfer to a problem-solving task. However, real-world analogizing often involves the consideration of multiple source experiences when attempting to identify a potential solution to a problem. Moreover, truly creative and innovative analogies are often generated by going *beyond* the most accessible source and identifying a seemingly-dissimilar but nevertheless relevant source from which to draw inspiration.

As such, a critical next step in understanding the role of focused and diffuse attention in spontaneous analogical transfer will be to move to a paradigm including multiple potential sources (e.g. Catrambone & Holyoak, 1989). Particularly of interest will be the influence of these various attentional factors on the ability of an individual to spontaneously transfer an analogous solution strategy from a superficially dissimilar source in the face of a superficially similar source.

The addition of a distracting story could be expected to affect the relationships identified in this study in a variety of ways. In the present research, the diffuse attention factor was related to the completeness of an individual's story representation. In this case, that completeness was facilitative, as the story was relevant to solution and its elaborate encoding aided its retrieval. However, in a paradigm involving a superficially similar, distracting story, the elaborate encoding of the distracting source may serve to increase the interference from that source and reduce transfer from the superficially dissimilar source. Alternately, however, given that diffuse attention is also suggested to relate to the likelihood of considering potentially irrelevant or distant sources, it is possible that this diffuse attention would positively relate to the identification of a more distant source in a multiple-source paradigm (similar to its role in facilitating remote associate identification in the RAT).

The same contrasting predictions could be made for the focused attention factor as well. If focus is necessary to suppress consideration of the superficially similar source prior to consideration of the analogous source, then it should be more predictive than in the present paradigm. However, if focus is related to an inhibition of the dissimilar source, than it may be less related to solution success.

A study examining this multiple source question is currently being conducted, using the Lightbulb story and a more superficially similar, but disanalogous, source derived from the materials of Bearman et al. (2011). However, additional materials could also be employed, such as those developed by Ross and colleagues (e.g. Blessing & Ross, 1996; Ross, 1989), to investigate the transfer of algebra strategies in the presence or absence of superficial similarity. The use of a variety of source-target combinations would validate any individual difference relationships identified in this research.

D. **Conclusion**

This study provides an important step towards understanding the role of individual differences in attention and executive function in spontaneous analogical transfer. It moves beyond initial research in focused attention and analogical mapping by examining the roles of both focused and diffuse attention across a process involving noticing, retrieval, and mapping. This study also identifies the importance of an individual's representation of the source, both its completeness and the inclusion of the problem-solving constraint, on spontaneous transfer in this task. The idea of identifying and aligning analogous constraints on problem-solving as driving spontaneous noticing is a novel finding and worth further investigation. Further, the relationship between the attentional factors and spontaneous transfer was found to remain even after controlling for variation in a participant's representation. Given the proposed importance of

analogical transfer as a problem-solving mechanism, a full understanding of the role that diffuse attention plays in facilitating that transfer will be critical for developing an accurate model of analogical processes.

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APPENDIX A

ALTERNATIVE SOURCE TEXT VERSIONS

The Wine Merchants

One day a rich man found that his wine cellar was empty. So he sent out messengers to announce a generous offer. The first person to bring the rich man a barrel of wine would be given a brick of solid gold. However, the offer would expire at sundown.

Two wine merchants heard the news. Each had a horse-drawn cart loaded with large barrels of wine. They both set out for the duke's palace at once. An hour before sundown they came to a place where the bridge had been washed out by a raging river. The first merchant drove his horses and cart into the flood in a desperate attempt to reach the other side. But the horses were already exhausted and could not fight the current. The cart overturned, and the horses, wine, and driver were washed away.

The second merchant tried a different tactic. He poured the wine out of all but one of his barrels, and lashed them together to form a raft; then he loaded the one full barrel, a horse, and himself on top. He set the raft adrift and floated downstream. In a few minutes the raft came to rest on the short in front of the town where the rich man lived. The merchant disembarked, loaded the wine barrel on the horse, and led it to the rich man's house. He arrived just as the sun was setting, and collected the gold brick as a reward for his efforts.

The General

A small country was ruled from a strong fortress by a dictator. The fortress was situated in the middle of the country, surrounded by farms and villages. Many roads led to the fortress through the countryside. A rebel general vowed to capture the fortress. The general knew that an attack by his entire army would capture the fortress.

He gathered his army at the head of one of the roads, ready to launch a full-scale direct attack. However, the general then learned that the dictator had planted mines on each of the roads.

The mines were set so that small bodies of men could pass over them safely, since the dictator needed to move his troops and workers to and from the fortress. However, any large force would detonate the mines. Not only would this blow up the road, but it would also destroy many neighboring villages. It therefore seemed impossible to capture the fortress.

However, the general devised a simple plan. He divided his army into small groups and dispatched each group to the head of a different road. When all was ready, he gave the signal and each group marched down a different road. Each group continued down its road to the fortress so that the entire army arrived together at the fortress at the same time. In this way, the general captured the fortress and overthrew the dictator.

The Fire Chief

One night a fire broke out in a wood shed full of timber on Mr. Johnson's place. As soon as he saw flames he sounded the alarm, and within minutes dozens of neighbors were on the scene armed with buckets. The shed was already burning fiercely, and everyone was afraid that if it wasn't controlled quickly the house would go up next.

Fortunately, the shed was right beside a lake, so there was plenty of water available. If a large volume of water could hit the fire at the same time, it would be extinguished. But with only small buckets to work with, it was hard to make any headway. The fire seemed to evaporate each bucket of water before it hit the wood. It looked like the house was doomed.

Just then the fire chief arrived. He immediately took charge and organized everyone. He had everyone fill their bucket and then wait in a circle surrounding the burning shed. As soon as the last man was prepared, the chief gave a shout and everyone threw their bucket of water at the fire. The force of all the water together dampened the fire right down, and it was quickly brought under control. Mr. Johnson was relieved that his house was saved, and the village council voted the fire chief a raise in pay.

APPENDIX B

LIGHTBULB SUMMARY CODING

For all participants, identify if "The Lightbulb" summary includes these concepts.

Their wording does not have to match exactly, but they only need to write something that maps generally onto one of these concepts.

Yes = 1

No = 0

Concepts:

1. A high-intensity wave could repair the lightbulb/jar apart the fused parts. (SC1)

2. A high-intensity ultrasound wave would also break the glass. (SC2)

3. She used several ultrasound machines. (SC3)

4. She administered low-intensity waves. (SC4)

5. She administered waves from several directions. (SC5)

6. She administered the waves simultaneously/all at once. (SC6)

7. The waves converged/combined to repair the lightbulb/jar apart the fused parts. (SC7)

8. Since low intensity waves were used, the glass was left intact. (SC8)

APPENDIX C

ANALYSES OF MONOLINGUALS' AND BILINGUALS' EXECUTIVE FUNCTIONING AND ANALOGICAL TRANSFER PERFORMANCE

Prior work has suggested advantages in both executive function and divergent thinking for bilingual versus monolingual individuals. In her review on bilingualism and creativity, Ricciardelli (1992) found that, in 20 of the 24 reviewed articles, bilingual individuals outperform monolingual individuals on divergent thinking tasks. Further, early bilingual children demonstrate advantages over their monolingual peers on several tasks tapping attentional control including task switching in dimensional-change card-sort tasks (Bialystok & Martin, 2004) and recognizing multiple interpretations of ambiguous-figure and figure-ground illusions (Bialystok & Shapero, 2005).

Importantly, early bilinguals have shown advantages in solving insight problems (Cushen & Wiley, 2011), another type of problem which has been hypothesized to require both focused and diffuse attention (Ansburg & Hill, 2003; Guilford, 1956; Martindale, 1995; Schooler, 2002; Smallwood & Schooler, 2006). This suggests that, if spontaneous analogical transfer depends on a similar combination of attentional resources, early bilinguals may be expected to demonstrate advantages relative to monolinguals.

To test this possibility, two sets of analyses were conducted. The first set of analyses assessed whether bilinguals demonstrated consistent differences on the measures of focused attention, diffuse attention, and flexibility obtained in this study. The second set of analyses assessed whether bilinguals demonstrated advantages in spontaneous analogical transfer. Bilingualism information was collected during a mass-testing session prior to the analogical study session. On the basis of this pre-screening, 85 individuals could be clearly coded as either

early bilinguals (who reported fluency in multiple languages prior to the age of 6; 37 individuals), late bilinguals (who reported fluency in multiple languages, but who had acquired one after the age of 6; 24 individuals) and monolinguals (who reported fluency only in one language; 24 individuals). Table C.1 describes differences in years speaking English and reported English fluency (out of 10) as a function of language group.

TABLE C.I.

AVERAGE YEARS SPEAKING ENGLISH, REPORTED FLUENCY, AND READING WITH DISTRACTION TIME AS A FUNCTION OF LANGUAGE GROUP

Measure	Early Bilinguals	Late Bilinguals	Monolinguals
Years Speaking English	16.11 (2.49)	13.39 (5.10)	18.54 (2.39)
Reported English Fluency (out of 10)	9.68 (.74)	9.39 (1.16)	10.00 (0.00)
Total Read w/ Dist Time (msec)	178803.50 (42948.43)	186231.42 (48439.10)	174479.29 (31050.28)

Note. Values in parentheses represent standard deviations.

Table C.2 summarizes the means and standard deviations of performance on the individual difference tasks as a function of language group, as well as the F-statistic identifying intra-group differences. Only on one measure, Remote Associate accuracy, were language groups found to be significantly different from one another. However, this effect was driven by stronger performance by monolinguals when compared to either early bilinguals, $t(59) = 1.99$, $p = .051$, or to late bilinguals, $t(46) = 3.09$, $p = .003$. No differences were identified between the two bilingual groups, $t(59) = 1.48$, $p = .14$.

TABLE C.II

PERFORMANCE ON INDIVIDUAL DIFFERENCE MEASURES AS A FUNCTION OF LANGUAGE GROUP

Measure	Early Bilinguals	Late Bilinguals	Monolinguals	*F*
Antisaccade Acc	.85 (.10)	.80 (.15)	.80 (.19)	1.08
WMC Composite	.58 (.14)	.53 (.14)	.55 (.16)	1.10
Read w/ Dist Errors	9.97 (11.04)	12.79 (20.81)	15.09 (24.49)	.56
Average Navon RT	977.15 (191.57)	1027.34 (239.17)	936.35 (228.23)	.99
Navon Incong Acc Cost	.06 (.10)	.06 (.09)	.07 (.08)	.14
RAT Accuracy	.41 (.17)	.34 (.19)	.49 (.13)	4.65*
Anagram Acc	.56 (.17)	.54 (.11)	.61 (.17)	1.21
Benefit from Hints	.02 (.20)	.11 (.21)	.04 (.19)	1.47
Navon Mix Cost	570.16 (346.99)	596.77 (346.83)	488.57 (241.71)	.70
Navon Switch Cost	407.17 (267.02)	274.79 (256.55)	415.37 (355.19)	1.74
Vis Search Mix Cost	-23.26 (160.43)	32.78 (168.91)	-23.82 (272.10)	.66
Vis Search Switch Cost	136.85 (174.48)	159.73 (187.24)	158.64 (176.19)	.16

Note. Values in parentheses represent standard deviations. * $p < .05$

Thus, contrary to prior research suggesting advantages in inhibition (Bialystok, Craik, Klein, & Viswanathan, 2004), divergent thinking (Ricciardelli, 1992), and task-switching (Bialystok & Martin, 2004) among early bilinguals, no advantages associated with bilingualism

were identified in this data set. This is in line with a recent review by Costa, Hernandez, Costa-Faidella, and Sebastian Galles (2009), that suggests these bilingual advantages are typically inconsistent across studies and notoriously difficult to identify in college-aged populations. The finding that bilinguals are somewhat disadvantaged in a verbal measure of creativity is also consistent with prior research suggesting that bilingual advantages in divergent thinking can be mitigated by using verbal-based creativity measures (e.g. Argulewicz & Kush, 1984)

Given that few differences were identified between language groups in terms of individual difference measures, one might expect few differences between these groups also in terms of the analogy DVs of interest. Table C.3 summarizes these outcomes as a function of language group. Indeed, no differences were identified as a function of language group.

In contrast to Cushen and Wiley (2011), bilinguals did not demonstrate advantages in another task that seems to require both focused and diffuse attention: analogical transfer. A likely explanation for this difference is the verbal nature of the analogy task. While the materials used in Cushen and Wiley (2011) were primarily spatial and mathematical, the analogical transfer materials used here were inherently verbal. As verbal materials have been shown to mitigate bilingual advantages in creativity (Argulewicz & Kush, 1984), it seems possible that the nature of the task reduced the influence of bilingualism.

TABLE C.III

PERFORMANCE ON SPONTANEOUS TRANSFER, PROMPTED RETRIEVAL, MAPPING, AND REPRESENTATION AS A FUNCTION OF LANGUAGE GROUP

Measure	Early Bilinguals	Late Bilinguals	Monolinguals	*F*
Spontaneous Transfer	.54 (.51)	.58 (.50)	.58 (.50)	.08
Prompted Retrieval	.76 (.43)	.79 (.41)	.92 (.28)	1.26
Mapping Ability	7.97 (2.33)	8.5 (1.82)	8.5 (2.3)	.60
SC2	.62 (.49)	.79 (.41)	.63 (.49)	1.10
Convergence Schema	.48 (.28)	.55 (.20)	.53 (.20)	.62
Total Summary	.49 (.28)	.54 (.29)	.57 (.27)	.70

Note. Values in parentheses represent standard deviations.

An interesting question for future research is whether bilinguals might demonstrate advantages in analogical transfer using spatial materials. For example, Casakin and Goldschmidt (1999) have examined architects' willingness to use images (ranging from building schematics to other-domain images such as plants or logos) in solving a novel problem. A paradigm such as this, that examines whether participants are better able to notice, retrieve, and make us of previously-presented analogous images in a spatial design task, may be more likely to identify bilingual advantages, if they exist.

APPENDIX D

ANALOGY MATERIALS USED IN STUDY 3

PIN#:_____

READING

PACKET

On the following page is a brief story.

You will have 3 minutes to read the story.

Please pay close attention while reading, as you will be asked to summarize and rate the story on understandability.

Do NOT turn the page until instructed by the experimenter.

The Lightbulb

In a physics lab at a major university, a very expensive lightbulb which would emit precisely controlled quantities of light was being used in some experiments. Ruth was the research assistant responsible for operating the sensitive lightbulb. One morning she came into the lab and found to her dismay that the lightbulb no longer worked. She realized that she had forgotten to turn it off the previous night. As a result, the lightbulb overheated and the two wires in the filament inside the bulb fused together. The surrounding glass bulb was completely sealed, so there was no way to open it. Ruth knew that the lightbulb could be repaired if a brief, high-intensity ultrasound wave could be used to jar apart the fused parts. Furthermore, the lab had the necessary equipment to do the job.

However, a high-intensity ultrasound wave would also break the fragile glass surrounding the filament. At lower intensities the ultrasound wave would not break the glass, but neither would it jar apart the fused parts. So it seemed that the lightbulb could not be repaired, and a costly replacement would be required.

Ruth was about to give up when she had an idea. She placed several ultrasound machines in a circle around the lightbulb, and administered low-intensity ultrasound waves from several directions all at once. The waves all converged on the filament, where their combined effect was enough to jar apart the fused parts. Since each spot on the surrounding glass received only a low-intensity wave from one ultrasound machine, the glass was left intact. Ruth was greatly relieved that the lightbulb was repaired, and she then went on to successfully complete the experiment.

Do NOT turn the page until instructed by the experimenter.

How difficult to understand was "The Lightbulb"? (Circle one.)

1 2 3 4 5 6 7 8 9 10

Very Easy Very Difficult

Take 5 minutes to summarize the story that you just read.

You may look back to the story if necessary while writing your summary.

PIN#:_____

PROBLEM

SOLVING

PACKET

On the following page is a hypothetical medical problem.

You will have 5 minutes to produce as many possible solutions as you can identify to the problem.

Consider these solutions as suggestions to doctors, so don't worry about whether you have enough technical knowledge to execute the solution yourself.

Write your solutions below the problem and number each individual solution.

Do NOT turn the page until instructed by the experimenter.

The Ray Problem

Suppose you are a doctor faced with a patient who has a malignant tumor in his stomach. It is impossible to operate on the patient, but unless the tumor is destroyed the patient will die.

There is a kind of ray that can be used to destroy the tumor. If the rays reach the tumor all at once at sufficiently high intensity, the tumor will be destroyed. Unfortunately, at this intensity the healthy tissue that the rays pass through on the way to the tumor will also be destroyed. At lower intensities the rays are harmless to healthy tissue, but they will not affect the tumor either.

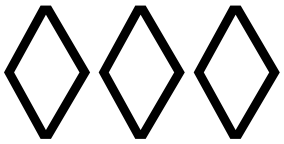
What type of procedure might be used to destroy the tumor with the rays, and at the same time avoid destroying the healthy tissue?

Possible Procedures

If you need more space, turn to the next page.

Possible Procedures Continued

Do NOT turn the page until instructed by the experimenter.



How difficult to understand was "The Ray Problem"? (Circle one.)

1 2 3 4 5 6 7 8 9 10

Very Easy Very Difficult

Do NOT turn the page until instructed by the experimenter.

You will now have 5 more minutes to produce as many additional solutions as you can think to the Ray Problem.

When trying to solve the Ray Problem, some people have found it easier if they consider the story that you read earlier.

Now try to think of a solution to the Ray Problem that is suggested in the earlier story.

Again, remember to write your solutions below the problem and number each individual solution.

Turn the page to begin.

The Ray Problem

Suppose you are a doctor faced with a patient who has a malignant tumor in his stomach. It is impossible to operate on the patient, but unless the tumor is destroyed the patient will die.

There is a kind of ray that can be used to destroy the tumor. If the rays reach the tumor all at once at sufficiently high intensity, the tumor will be destroyed. Unfortunately, at this intensity the healthy tissue that the rays pass through on the way to the tumor will also be destroyed. At lower intensities the rays are harmless to healthy tissue, but they will not affect the tumor either.

What type of procedure might be used to destroy the tumor with the rays, and at the same time avoid destroying the healthy tissue?

Possible Procedures

If you need more space, turn to the next page.

Possible Procedures Continued

Do NOT turn the page until instructed by the experimenter.

Ray Problem Questionnaire

1. Prior to the hint, did it occur to you to make use of the story presented earlier in the experiment when solving the Ray Problem? YES NO

2. How helpful was this earlier story in solving the Ray Problem?

   1 2 3 4 5 6 7 8 9 10
   Very Harmful Very Helpful

3. What solution to the Ray Problem was suggested by the story presented earlier?

   _____

   _____

   _____

   _____

   _____

   _____

4. Have you seen the Ray Problem or a similar problem prior to this experiment?
   YES NO

   If YES, please describe the problem and where you saw it:

   _____

   _____

   _____

   _____

APPENDIX E

READING WITH DISTRACTION TASK MATERIALS

Reading with Distraction - Condition A

Story 1

The car ride house *was getting bumpy* teeth *now that* religious *George had* dodge *left the main* tools *road to use the* airline *dirt road. He* proud *was out of* yearn *school, not having* evoke *to study* river *during the summer* teeth *break. He was* dodge *glad to* male *get out of* yearn *the stuffy* teeth *offices* evoke *of the archaeology* tractor *department* sprinkler *and get out into* river *the field. He* river *always liked going* harp *on archaeology* dodge *digs. He read that* evoke *this dig was trying* sound *to uncover* dodge *some artifacts at a* person *suspected* kayak *Indian burial site. The* yearn *site was located* evoke *near a small lake in* teeth *the back* barrel socks *country. George* yearn *felt the excitement* teeth *building up* river *inside himself. He* dodge *heard the joyous jingle of* yearn *his digging* tailspin *equipment as he hit* evoke *the various bumps* river *and hills* camp *in the road. He* silhouette *smiled eagerly* painting *with anticipation.*

Story 2

The dentist's waiting canal *room was quite full* giant *when Sam* momentous *arrived. He waited* yield *for the blond receptionist* raven *to stop chatting online* vigor *with her friend* honorable *and checked in. She said that* salad *the dentist* major *was running* giant *behind schedule. Sam* yield *took a* trumpet *seat by* vigor *the front* giant *door and* salad *found a sports magazine* horoscope *that looked* major *interesting. The cover* spinach *was torn, but* major *at least it was* harp *a current* yield *issue. The receptionist* salad *called another* radio *person into* yield *the office. Sam* ferret *read an* arbitration *article about new* vigor *restaurants. The man* salad *next to him* giant *groaned and* gun boats *held his* vigor *jaw. Sam could* giant *see that he* major *was in* yield *pain. He was* vigor *glad this was* top hat *just a check up* salad *visit. He hoped* major *that he* baseball *would not have* razor *any deep* appearance *cavities.*

Reading with Distraction - Condition B

Story 1

The car ride house *was getting bumpy* bland *now that* religious *George had* clean *left the main* tools *road to use the* airline *dirt road. He* proud *was out of* dream *school, not having* candy *to study* white *during the summer* bland *break. He was* clean *glad to* male *get out of* dream *the stuffy* bland *offices* candy *of the archaeology* tractor *department* sprinkler *and get out into* white *the field. He* white *always liked going* harp *on archaeology* clean *digs. He read that* candy *this dig was trying* sound *to uncover* clean *some artifacts at a* person *suspected* kayak *Indian burial site. The* dream *site was located* candy *near a small lake in* bland *the back* barrel socks *country. George* dream *felt the excitement* bland *building up* white *inside himself. He* clean *heard the joyous jingle of* dream *his digging* tailspin *equipment as he hit* candy *the various bumps* white *and hills* camp *in the road. He* silhouette *smiled eagerly* painting *with anticipation.*

Story 2

The dentist's waiting canal *room was quite full* knows *when Sam* momentous *arrived. He waited* paper *for the blond receptionist* raven *to stop chatting online* nasty *with her friend* honorable *and checked in. She said that* valet *the dentist* zebra *was running* knows *behind schedule. Sam* paper *took a* trumpet *seat by* nasty *the front* knows *door and* valet *found a sports magazine* horoscope *that looked* zebra *interesting. The cover* spinach *was torn, but* zebra *at least it was* harp *a current* paper *issue. The receptionist* valet *called another* radio *person into* paper *the office. Sam* ferret *read an* arbitration *article about new* nasty *restaurants. The man* valet *next to him* knows *groaned and* gun boats *held his* nasty *jaw. Sam could* knows *see that he* zebra *was in* paper *pain. He was* nasty *glad this was* top hat *just a check up* valet *visit. He hoped* zebra *that he* baseball *would not have* razor *any deep* appearance *cavities.*

APPENDIX F

ANAGRAM TASK MATERIALS

Problem	Solution	Hint Set
1. snowk	knows	B
2. lndba	bland	B
3. ogedd	clean	A
4. gtian	knows	A
5. elcna	clean	B
6. etteh	teeth	A
7. yldie	yield	A
8. alvet	valet	B
9. hetiw	white	B
10. eynar	yearn	A
11. daync	candy	B
12. virer	river	A
13. amrjo	major	A
14. tasny	nasty	A
15. vrgio	vigor	A
16. rappe	paper	B
17. sldaa	salad	A
18. eoevk	evoke	A
19. aedmr	dream	B
20. earbz	zebra	B

APPENDIX G

REMOTE ASSOCIATE TASK PROBLEMS AND SOLUTIONS

Problem #	Cue Word 1	Cue Word 2	Cue Word 3	Solution
1	BLUE	CAKE	COTTAGE	CHEESE
2	GRAVY	SHOW	TUG	BOAT
3	SANDWICH	GOLF	FAN	CLUB
4	ATTORNEY	SPENDING	SELF	DEFENSE
5	SURPRISE	LINE	BIRTHDAY	PARTY
6	NIGHT	WRIST	STOP	WATCH
7	DUCK	FOLD	DOLLAR	BILL
8	FOUNTAIN	BAKING	POP	SODA
9	SAFETY	CUSHION	POINT	PIN
10	CRACKER	FLY	FIGHTER	FIRE
11	MEASURE	WORM	VIDEO	TAPE
12	PRINT	BERRY	BIRD	BLUE
13	FLOWER	FRIEND	SCOUT	GIRL
14	DATE	ALLEY	FOLD	BLIND
15	FUR	RACK	TAIL	COAT
16	HOUND	PRESSURE	SHOT	BLOOD
17	PEACH	ARM	TAR	PIT
18	WHEEL	HAND	SHOPPING	CART
19	MILL	TOOTH	DUST	SAW
20	BOOT	SUMMER	GROUND	CAMP
21	TANK	HILL	SECRET	TOP
22	EIGHT	SKATE	STICK	FIGURE
23	RAIN	TEST	STOMACH	ACID
24	SPOON	CLOTH	CARD	TABLE
25	CRY	FRONT	SHIP	WAR

APPENDIX H

HINTED TRANSFER RESULTS

One way researchers have investigated the ability of individuals to successfully map between source and target is to examine post-hint transfer. While spontaneous transfer requires participants to both notice and make use of a prior analog, hinted transfer requires only that participants retrieve and make use of that analog. In this way, examining the predictors of post-hint transfer may clarify what factors are facilitating transfer in the absence of the need for spontaneous noticing.

Of the 58 individuals who did not generate the convergence solution prior to the hint, 26 (45%) were able to generate the convergence solution post-hint (in the last 5 minutes of problem solving). A logistic regression was conducted predicting hinted transfer as a function of the individual difference factors. This regression is described in Table G.1.

To summarize, a model including the focused attention factor significantly predicted hinted transfer, with the focused attention factor serving as a significant predictor. The addition of the diffuse attention factor in the second block resulted in a marginal increase in model fit, with only the diffuse attention factor appearing as a marginal predictor.

These results are consistent with prior research indicating that measures of focused attention (such as working memory capacity or antisaccade performance) relate to an individual's ability to accurately draw mapping across two representations. However, these results should be considered cautiously for multiple reasons. First, the sample size for the analysis ($N = 47$) is drastically reduced relative to the whole sample. Second, there is an unavoidable selection effect associated with examining only those individuals who did not spontaneously generate the convergence solution. As such, while these results are consistent with

predictions regarding the influence of individual difference factors on success, measures of mapping that are less susceptible to the above-mentioned limitations are included in the main manuscript.

TABLE G.I
LOGISTIC REGRESSION PREDICTING HINTED TRANSFER BY INDIVIDUAL DIFFERENCE FACTORS

	B	***S.E.***	***Wald***	R^2	X^2	ΔX^2
Block 1				.14	5.00*	
Focused	1.23	.60	4.24*			
Block 2				.22	8.35*	$3.35^{\dagger}$
Focused	.1.00	.63	2.54			
Diffuse	.97	.56	$2.96^{\dagger}$			

Note: ** $p < .01$, *$p < .05$, † $p < .10$ for $N = 47$.

APPENDIX I

FACTOR ANALYSIS OF STORY SUMMARIES

The analyses reported earlier in this study investigate the relationships between the individual difference factors, analogical transfer outcomes, and several measures of representation as well as the role of those representation measures in mediating the influence of the individual difference factors on analogical transfer. These measures of story representation were identified *a priori* as interesting to analyses, due to prior research investigating their impact (in the case of the convergence solution) and due to the relationships identified in Study 2 (in the case of the constraint statement, SC2). However, given that initial story summaries were obtained for all individuals, it is possible to conduct a factor analysis to provide a more detailed description of the clustering of concepts within the story summaries.

To accomplish this goal, the contents of all participants' story summaries from Study 3 were submitted to a principle components factor analysis. Factors were rotated with varimax rotation to identify distinct sources of variance. The resulting analysis identified 3 factors that accounted for 59.27% of the variance in story summaries. Factor loadings as well as concept inclusion rates are shown in Table I.I. To summarize, these factors corresponded to 1) ideas related to the convergence solution, 2) ideas related to the initial description of the problem (including the need for a strong force and the constraint on its use) and 3) ideas related to the resolution of the problem (including the combination of forces and the avoiding of negative outcomes). The correlations between each of these factors and the analogical transfer and mapping outcomes are shown in Table I.2.

TABLE I.I
FACTOR ANALYSIS OF STORY CONCEPTS

Story Concept	Rate of Inclusion	Factor Analysis		
		Convergence Factor	Description Factor	Resolution Factor
SC1	.48	.08	.86	.11
SC2	.64	.11	.87	-.01
SC3	.71	.74	.08	.16
SC4	.73	.75	.11	.25
SC5	.68	.68	.14	-.35
SC6	.11	.11	.29	.34
SC7	.18	.01	.03	.81
SC8	.35	.50	.04	.52

TABLE I.II
CORRELATIONS BETWEEN REPRESENTATION, ANALOGY MEASURES, AND INDIVIDUAL DIFFERENCE MEASURES

Analogy Measures	**Convergence Factor**	**Description Factor**	**Resolution Factor**	**Total Summary**
Spontaneous Transfer	.08	.33**	.12	.29**
Prompted Retrieval	.20*	.28**	.06	.32**
Story Helpfulness	.21**	.29**	.15†	.37**
Individual Difference Factor				
Focused Attention	.09	.13	.26*	.23*
Diffuse Attention	.19*	.06	.11	.22*

Note: ** $p < .01$, * $p < .05$ for $N = 120$

Perhaps not surprisingly, a "Convergence" factor did fall out from these summaries. Interestingly, it is not completely consistent with prior characterizations of the convergence schema. That is, the factor identified in the current data included the following concepts:

SC3. She used several ultrasound machines.

SC4. She administered low-intensity waves.

SC5. She administered waves from several directions.

The classical characterization of the convergence schema (e.g. Gick & Holyoak, 1983; Catrambone & Holyoak, 1989) does not include SC3, but instead includes a temporal convergence concept (represented here as SC6: She administered the waves simultaneously/all at once.). Participants tended to leave this last idea implicit, as it was the least included concept in all participants' story summaries (only 11% of participants included it). Instead, participants tended to report SC3 at a higher rate (71%). Overall, the three concepts included in this revised convergence schema were the most-included concepts in the story summaries.

However, variability in this factor was not found to relate to spontaneous analogical transfer. Regardless of how well-represented these concepts were in a participant's story summary, it did not seem to influence their likelihood of spontaneously noticing and making use of "The Lightbulb" when solving the Ray Problem. The convergence factor was related both to prompted retrieval and to rated story helpfulness. This is consistent with the idea that a representation of the convergence schema may help transfer once the association between the source and target has been noticed, but does not facilitate that initial noticing.

The second factor, the "Description" factor, included both the problem statement and the constraint on solution. These concepts were slightly less common than those included in the

convergence schema. Nevertheless, variance in their inclusion was a significant predictor of all analogical outcomes. Not only was it the only measure related to the likelihood of spontaneous transfer, but it was also related to prompted retrieval and rated story helpfulness. This result is consistent with the prior discussion of the importance of the constraint statement in facilitating initial noticing of the similarity between the source and the target. As with the constraint statement alone, no individual difference factor related to the description factor. As such, the inclusion of these concepts seems to be a primary determinant of spontaneous noticing between source and target.

Finally, a "Resolution" factor was also identified and was primarily determined by the lesser-included final concepts of the story. These final concepts describe the fact that the convergence solution was successful due to the strength of the forces at a central point (the lightbulb filament), and the weakness the forces at decentralized points (the lightbulb glass). While not relating either to spontaneous transfer or prompted retrieval, variance in this factor was marginally related to a participant's assessment of the helpfulness of the story.

APPENDIX J

READING ABILITY, REPRESENTATION, AND SPONTANEOUS TRANSFER

Total time on the Reading with Distraction task was used as a measure of reading ability in this research. This measure was related to ACT Reading scores for those individuals who reported their scores during mass testing, r (81) = -.51, $p < .001$, but unrelated to ACT Math scores, r (82) = -.14, $p = .22$. The reading ability measure correlated to both the focused and the diffuse attention factors, as well as to the total story summary. As such, a linear regression was conducted to assess whether controlling for differences in reading ability mitigated the influence of these factors on story representation. Table J.1 describes this analysis.

TABLE J.I

LINEAR REGRESSION PREDICTING COMPLETENESS OF THE STORY SUMMARY BY READING ABILITY AND THE DIFFUSE ATTENTION FACTOR.

	B	***S.E.***	**β**	***t***	R^2	$F(R^2)$	ΔR^2	$F(\Delta R^2)$
Block 1					.04	4.56*		
Reading Ability	-1.26E-6	.00	-.21	-2.14*				
Block 2					.05	3.59*	.02	2.54
Reading Ability	-8.21E-7	.00	-..14	-1.27				
Focus	.06	.04	.17	1.60				
Block 3					.04	2.42†	.00	.14
Reading Ability	-7.59E-7	.00	-.13	-1.14				
Focus	.05	.04	.16	1.35				
Diffuse	.02	.04	.04	.37				

Note: *$p < .05$, † $p < .10$ for $N = 99$.

To summarize, after controlling for reading ability in the first block, the addition of the focused attention factor in the second block failed to explain any additional variance. The further addition of the diffuse attention factor also failed to explain additional variance.

These results suggest the possibility that the relationship between the focused and diffuse attention measures and spontaneous transfer may also be reduced by controlling for reading ability. To investigate this question a logistic regression was conducted controlling for both story representation and reading ability prior to assessing the roles of the focused and diffuse attention factors. Table J.2 describes this regression.

To summarize, after controlling for the story representation in the first block, the addition of reading ability into the second block of the regression did not significantly improve the predictiveness of the model. However, the addition of the focused attention factor in the third block did significantly increase model fit, as did the addition of the diffuse attention factor in the fourth block. These results suggest that, while reading ability relates to the quality of an individual's story summary, and while the quality of that summary predicts spontaneous transfer, differences in reading ability cannot explain the roles of the focused or diffuse attention factors in predicting spontaneous transfer. Indeed, the inclusion of the reading ability measure did not improve prediction of spontaneous generation of the convergence solution and did not seem to influence the relationship between the individual difference factors and the likelihood of spontaneous convergence solution either.

TABLE J.II

LOGISTIC REGRESSION PREDICTING SPONTANEOUS GENERATION OF THE CONVERGENCE SOLUTION BASED ON THE TOTAL STORY SUMMARY, READING ABILITY, THE FOCUSED ATTENTION FACTOR, AND THE DIFFUSE ATTENTION FACTOR

	B	***S.E.***	***Wald***	R^2	X^2	ΔX^2
Block 1				.13	10.25**	
Total Summary	2.76	.92	9.05**			
Block 2				.15	11.86**	1.61
Total Summary	2.58	.93	7.64			
Reading Ability	.00	.00	1.58			
Block 3				.29	24.09**	12.23**
Total Summary	2.49	1.01	6.10*			
Reading Ability	.00	.00	.08			
Focused	1.25	.40	9.93			
Block 4				.33	28.67**	4.58*
Total Summary	2.56	1.05	6.00*			
Reading Ability	.00	.00	.68			
Focused	.1.05	.41	6.60**			
Diffuse	.79	.38	4.27*			

Note: ** $p < .01$, *$p < .05$, † $p < .10$ for $N = 100$.

UNIVERSITY OF ILLINOIS
AT CHICAGO

Office for the Protection of Research Subjects (OPRS)
Office of the Vice Chancellor for Research (MC 672)
203 Administrative Office Building
1737 West Polk Street
Chicago, Illinois 60612-7227

Approval Notice
Continuing Review

April 5, 2011

Jennifer Wiley, PhD
Psychology
1054-D B.S.B., M/C 285
Chicago, IL 60612
Phone: (312) 355-2501 / Fax: (312) 413-4122

RE: Protocol # 2001-0489
"Understanding in Science: Think-Aloud Studies"

Dear Dr./Mr./Ms. Wiley:

Your Continuing Review was reviewed and approved by the Expedited review process on March 20, 2011. You may now continue your research.

Please note the following information about your approved research protocol:

Protocol Approval Period: April 11, 2011 - April 9, 2012
Approved Subject Enrollment #: 5000 (2889 subjects enrolled)
Additional Determinations for Research Involving Minors: The Board determined that this research satisfies 45CFR46.404, research not involving greater than minimal risk.
Performance Site: UIC
Sponsor: National Science Foundation
PAF#: **Not available**
Grant/Contract No: **Not available**
Grant/Contract Title: ROLE: Understanding in Science
Research Protocol:

a) Understanding in Science: Think-Aloud Studies, per grant application, as submitted to OPRS on 10/22/01 (UIC Initial Research Protocol Application, last amended on 6/12/02)

Recruitment Material(s):

a) Amendment #2, Flier, 6/12/02
b) UIC Psychology Department Subject Pool recruitment procedures will be followed.

Informed Consents:

a) .5 hr Problem Solving PEC Agreement; Version 5; 02/10/2010
b) 1 hr Problem Solving PEC Agreement; Version 5; 02/10/2010
c) 2 hr Problem Solving PEC Agreement; Version 5; 02/10/2010
d) 1 hr Problem Solving Paid Consent; Version 5; 02/10/2010
e) 2 hr Problem Solving Paid Consent; Version 5; 02/10/2010
f) 1.5 hr Problem Solving Paid Consent; Version 5; 02/10/2010
g) .5 hr Problem Solving Paid Consent; Version 5; 02/10/2010
h) 1.5 hr Problem Solving PEC Agreement; Version 5; 03/12/2010

Parental Permission(s):

a) A waiver of parental permission has been granted under 45 CFR 46.116(d) and 45 CFR 46.408(c); however, as per UIC Psychology Subject Pool policy, as least one parent must sign the Blanket Parental Permission document prior to the minor subject's participation in the UIC Psychology Subject Pool.

Your research meets the criteria for expedited review as defined in 45 CFR 46.110(b)(1) under the following specific category:

(7) Research on individual or group characteristics or behavior (including but not limited to research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

Please note the Review History of this submission:

Receipt Date	Submission Type	Review Process	Review Date	Review Action
03/14/2011	Continuing Review	Expedited	03/20/2011	Approved

Please remember to:

→ Use your **research protocol number** (2001-0489) on any documents or correspondence with the IRB concerning your research protocol.

→ Review and comply with all requirements on the enclosure,
"**UIC Investigator Responsibilities, Protection of Human Research Subjects**"

Please note that the UIC IRB has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

Please be aware that if the scope of work in the grant/project changes, the protocol must be amended and approved by the UIC IRB before the initiation of the change.

We wish you the best as you conduct your research. If you have any questions or need further help, please contact OPRS at (312) 996-1711 or me at (312) 355-2764. Please send any correspondence about this protocol to OPRS at 203 AOB, M/C 672.

Sincerely,

Betty Mayberry, B.S.

IRB Coordinator, IRB # 2

Office for the Protection of Research Subjects

Enclosure(s):

1. **UIC Investigator Responsibilities, Protection of Human Research Subjects**
2. **Informed Consent Document(s):**
   a) .5 hr Problem Solving PEC Agreement; Version 5; 02/10/2010
   b) 1 hr Problem Solving PEC Agreement; Version 5; 02/10/2010
   c) 2 hr Problem Solving PEC Agreement; Version 5; 02/10/2010
   d) 1 hr Problem Solving Paid Consent; Version 5; 02/10/2010
   e) 2 hr Problem Solving Paid Consent; Version 5; 02/10/2010
   f) 1.5 hr Problem Solving Paid Consent; Version 5; 02/10/2010
   g) .5 hr Problem Solving Paid Consent; Version 5; 02/10/2010
   h) 1.5 hr Problem Solving PEC Agreement; Version 5; 03/12/2010
3. **Recruiting Material(s):**
   a) Amendment #2, Flier, 6/12/02
   b) UIC Psychology Department Subject Pool recruitment procedures will be followed.

cc: Gary E. Raney, Psychology, M/C 285
OVCR Administration, M/C 672

PATRICK J CUSHEN

CONTACT INFORMATION

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EDUCATION

Ph.D., 2012 University of Illinois at Chicago Chicago, IL
- Dissertation: *Analogical problem solving: A common explanation, but a rare observation*
- Major: Cognitive Psychology
- Minor: Cognitive Neuroscience
- Committee: Jennifer Wiley (Chair), James Pellegrino, Benjamin Storm, Michael Ragozzino, Thomas Ormerod (Lancaster University)

M.A., 2009 University of Illinois at Chicago Chicago, IL
- Thesis: *Combining load and individual differences to explore the role of working memory in problem solving*
- Committee: Jennifer Wiley (Chair), James Pellegrino, Martha Alibali

Honors B.A., 2005 Saint Louis University Saint Louis, MO
- Graduated Magna Cum Laude
- Major: Psychology
- Minors: Biology & Philosophy

AREAS OF SPECIALIZATION

Multilingualism
Executive Control
Working Memory Capacity
Domain Knowledge
Analogical Transfer
Creative Problem Solving
Collaborative Problem Solving
Gesture

RESEARCH GRANTS

University of Illinois at Chicago Chicago, IL
- Psi Chi Graduate Research Grant, 2011
  - Project Title: *Bilingualism and Analogical Problem Solving*

ACADEMIC AWARDS AND HONORS

University of Illinois at Chicago — Chicago, IL

- *Michael J Piorkowski Award for Excellence in Cognitive Psychology or Biopsychology, 2011*
- *Graduate Student Council Travel Award, 2011*
- *Psychology Department Travel Award, 2011*
- *Liberal Arts and Sciences PhD Student Travel Award, 2011*
- *Psychology Department Travel Award, 2010*
- *Graduate College Student Presenter Award, 2008*
- *Psychology Department Travel Award, 2008*
- *Graduate College Student Travel Award, 2007*
- *Psychology Department Travel Award, 2007*

Saint Louis University — Saint Louis, MO

- *Graduated Magna Cum Laude*, *2005*
- *Undergraduate Research Symposium, Excellence in Research Poster, 2004*
- *Xavier Leadership Scholarship, 2001-2005*
- *Honors Student Association, 2001-2005*
- *Dean's List*
- *Psi Chi, National Honor Society for Psychology, Inducted 2003*

PUBLICATIONS

Aiello, D. A., Jarosz, A. F., Cushen, P. J., & Wiley, J. (2012). Firing the executive: When an analytic approach to problem solving helps and hurts. *The Journal of Problem Solving, 4(2)*, Article 6.

Cushen, P. J., & Wiley, J. (2011). Aha! Voila! Eureka! Bilingualism and insightful problem solving. *Learning and Individual Differences, 21*, 458-462.

Wiley, J., Jarosz, A. F., Cushen, P. J., & Colflesh, G. J. H. (2011). Teaching an old bird new tricks: New rule use drives the relation between working memory capacity and Raven's Advanced Progressive Matrices. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37,* 256-263.

Ash, I. K., Cushen, P. J., & Wiley, J. (2009). Obstacles in investigating the role of restructuring in "insightful" problem solving. *Journal of Problem Solving, 2(2)*, Article 3.

Cushen, P. J., & Wiley, J. (2008). Upsides and downsides of gesturing in problem solving *Proceedings of the 30th Annual Conference of the Cognitive Science Society.*

Cushen, P. J., & Wiley, J. (2007). Evidence for incremental restructuring in a spatial insight problem. *Proceedings of the 29th Annual Conference of the Cognitive Science Society.*

MANUSCRIPTS IN PROGRESS

Cushen, P. J., & Wiley, J. (Invited resubmission). The relationship between cues to solution, solution patterns, and subjective reports of insight. *Consciousness & Cognition.*

Cushen, P. J., & Wiley, J. The role of working memory and spatial ability in the Tower of Hanoi task. *Manuscript in preparation.*

Cushen, P.J., & Wiley, J. Taking advantage of multiple perspectives in collaboration. *Manuscript in preparation.*

PRESENTATIONS

Cushen, P. J., & Wiley, J. (May, 2012). *Source representation and analogical transfer.* Poster to be presented at the Twenty-fourth Annual Convention of the Association for Psychological Science. Chicago, IL.

Wiley, J., Aiello, D. A., Jarosz, A. F., Cushen, P. J. (May, 2012). *Encouraging intuitive processing benefits creative problem solving.* Poster to be presented at the Twenty-fourth Annual Convention of the Association for Psychological Science. Chicago, IL.

Cushen, P. J., & Wiley, J. (November, 2011). *Individual differences and spontaneous transfer during analogical problem solving.* Poster presented at the Fifty-second Annual Meeting of the Psychonomic Society. Seattle, WA.

Aiello, D. A., Jarosz, A. F., Cushen, P. J., & Wiley, J. (April, 2011). *Firing the executive: When less control is more.* Paper presented at the Annual Meeting of the Midwestern Psychological Association. Chicago, IL.

Cushen, P. J., Jarosz, A. F., Aiello, D., & Wiley, J. (November, 2010). *Shifting Focus: The benefits of flexible control and diffuse attention.* Poster presented at the Fifty-first Annual Meeting of the Psychonomic Society. Saint Louis, MO.

Cushen, P. J., & Wiley, J. (August, 2010). *The roles of working memory capacity and spatial ability in first-time solution of the Tower of Hanoi.* Poster presented at the Annual Meeting of the Cognitive Science Society. Portland, OR.

Flores, J., Cushen, P. J., & Wiley, J. (July, 2010). *Bilingualism, Executive Control, and Insight Problem Solving*. Poster presented at the Committee on Institutional Cooperation Annual SROP Research Conference. Columbus, OH.

Cushen, P. J., & Wiley, J. (April, 2010). *Stranger in a strange land: Non-native status and insightful problem solving.* Paper presented at the Annual Meeting of the Midwestern Psychological Association. Chicago, IL.

Cushen, P. J., & Wiley, J. (April, 2010). *Aha! Voila! Eureka! Bilingualism and creative problem solving.* Paper presented at the Chicago Psychology Graduate Student Symposium. Chicago, IL.

Wiley, J., Jarosz, A.F., Cushen, P. J., Jensen, M. S., & Griffin, T. D. (November, 2009). *The power of three: Why the third person matters.* Paper presented at the Fiftieth Annual Meeting of the Psychonomic Society. Boston, MA.

Cushen, P. J., & Wiley, J. (November, 2008). *The relationship between cues to solution, restructuring patterns, and reports of insight.* Poster presented at the Forty-Ninth Annual Meeting of the Psychonomic Society. Chicago, IL.

Wiley, J., Cushen, P. J., Jarosz, A. F., & Jensen, M. S. (November, 2008). *The power of three in collaborative problem solving.* Poster presented at the Purdue Winer Memorial Lectures 'New Perspectives on Human Problem Solving' Workshop/Symposium. West Lafayette, IN.

Cushen. P. J., & Wiley, J. (July, 2008). *Upsides and downsides of gesturing in problem solving.* Paper presented at the Thirtieth Annual Conference of the Cognitive Science Society. Washington, DC.

Cushen, P. J., & Wiley, J. (May, 2008). *Gesture and problem solving: Not always a 'helping' hand.* Poster presented at the Twentieth Annual Convention of the Association for Psychological Science. Chicago, IL.

Cushen, P. J., & Wiley, J. (May, 2008). *The nature of restructuring and the "Aha!" experience in insight problem solving.* Poster presented at the Annual Meeting of the Midwestern Psychological Association. Chicago, IL.

Cushen, P. J., & Wiley, J. (August, 2007*). Evidence for incremental restructuring in a spatial insight problem.* Poster presented at the Twenty-Ninth Annual Conference of the Cognitive Science Society. Nashville, TN.

Colflesh, G., Wiley, J., & Cushen, P. J. (May, 2007). *Why do working memory tasks predict Raven's performance?* Poster presented at the Annual Meeting of the Midwestern Psychological Association. Chicago, IL.

Cushen, P. J., & Wiley, J. (April, 2006*). "...And then a miracle happens." An on-line look at insight.* Poster presented at the Sigma Xi, Graduate Research Symposium. University of Illinois at Chicago. Chicago, IL.

Barrios, S. L., Cushen, P. J., Salas, J., & Churchill, J. D. (November, 2005). *The effects of differential rearing conditions on reference and working memory in young F344/BN rats.* Poster presented at the Thirty-Fifth Annual Meeting of the Society for Neuroscience. Washington, DC.

DEPARTMENT COLLOQUIUM PRESENTATIONS

Cushen, P. J. & Wiley, J. (October, 2009). *Does multilingual or multicultural experience facilitate creativity?* Presentation at the Cognitive Psychology Division Brown Bag. University of Illinois at Chicago. Chicago, IL.

Cushen, P. J. (April, 2009). *Measuring representation and restructuring during insight.* Presentation at the Behavioral Neuroscience Division Brown Bag. University of Illinois at Chicago. Chicago, IL.

Cushen, P. J. & Wiley, J. (February, 2008). *The nature of insightful restructuring and the Aha! moment.* Presentation at the Cognitive Psychology Division Brown Bag. University of Illinois at Chicago. Chicago, IL.

Cushen, P. J. & Wiley, J. (May, 2006). *"...And then a miracle happens." An on-line look at insight.* Presentation at the Cognitive Psychology Division Brown Bag. University of Illinois at Chicago. Chicago, IL.

PROFESSIONAL EXPERIENCE

Research Associate

01/2012–Current University of Maryland Washington, DC
- Supervisor: Michael Bunting, Ph.D.
- Responsibilities: Research design; Data collection and analysis.
- Research on individual differences and problem solving.

Research Assistant: Cognition and eye-tracking laboratory.

09/2005–12/2011 Psychology Department, University of Illinois Chicago, IL
- Supervisor: Jennifer Wiley, Ph.D.
- Responsibilities: Research design; Data collection and analysis.
- Research on individual differences and problem solving.

Departmental IRB Assistant

09/2009-09/2011 Psychology Department, University of Illinois Chicago, IL
- Supervisor: Gary Raney, Ph.D.
- Responsibilities: Facilitate the organization and submission of Institutional Review Board applications; Maintain departmental records of IRB submissions.

Research Assistant: Behavioral neuroscience laboratory.

06/2004 – 05/2005 Psychology Department, Saint Louis University Saint Louis, MO
- Supervisor: James D. Churchill, Ph.D.
- Responsibilities: Data collection; Animal care.
- Completed the Saint Louis University course on animal care.

TEACHING EXPERIENCE

Instructor

01/2010 - 05/2010 Psychology Department, University of Illinois Chicago, IL
- PSCH 242, Introduction to Research in Psychology

Teaching Assistant
09/2010 – 12/2010 & Psychology Department, University of Illinois Chicago, IL
01/2007 – 12/2007
- PSCH 242, Introduction to Research in Psychology
- Instructor: Thomas Griffin, PhD.
- Responsibilities: Led two discussion sections per week. Held weekly office hours. Assisted in administering, grading, and providing feedback on in-class assignments and tests.

Teaching Assistant
01/2006 – 05/2006 Psychology Department, University of Illinois Chicago, IL
- PSCH 353, Laboratory in Cognition and Memory
- Instructor: Christopher Sanchez, MA.
- Responsibilities: Held weekly office hours. Assisted in constructing and conducting class experiments.

MENTORING OF UNDERGRADUATE STUDENTS

NAME	SEM	PROJECT TITLE
Meher Ahmed	F06	Individual Differences & Problem Solving
	S07	Individual Differences & Problem Solving
Krishna Amin	S10	Cues to Solution & Insightful Restructuring
	F10	Executive Control & Analogical Transfer
	S11	Executive Control & Analogical Transfer
Wesley Bauer	F06	Individual Differences & Problem Solving
	S07	Individual Differences & Problem Solving
Bradley Blumenthal	F06	Individual Differences & Problem Solving
Jamila Broachwala	F11	Executive Control & Analogical Transfer
Sarah Browne	F08	Individual Differences & Problem Solving
Anisa Chohan	S10	Cues to Solution & Insightful Restructuring
James Dalbec	S07	Individual Differences & Problem Solving
Zaineb Darabu	F08	Individual Differences & Problem Solving
Ramandeep Dhami	S11	Executive Control & Analogical Transfer
Jessica Flores	Sum10	Bilingualism & Insightful Problem Solving
Geline Goy	Sum07	Individual Differences & Problem Solving
Robert Hickson	F11	Executive Control & Analogical Transfer
Natalie Kats	S09	Individual Differences & Problem Solving
Rick Leonard	F11	Executive Control & Analogical Transfer
Anna Mankowska	F11	Executive Control & Analogical Transfer
Prerak Mehta	F08	Individual Differences & Problem Solving
Melissa Meinders	F11	Executive Control & Analogical Transfer
Natalia Olejarska	S10	Expertise & Group Problem Solving
Kelly Painter	S08	Individual Differences & Problem Solving
	F08	Individual Differences & Problem Solving
Toral Patel	S09	Expertise & Group Problem Solving
	F09	Expertise & Group Problem Solving
Nicholas Pinzke	F07	Individual Differences & Problem Solving
Ashley Pointer	S08	Individual Differences & Problem Solving
Arina Ratner	S09	Individual Differences & Problem Solving
	F09	Bilingualism & Insightful Problem Solving
Magen Rooney	Sum11	Executive Control & Analogical Transfer
Harleen Saini	F11	Executive Control & Analogical Transfer
Stephanie Stolen	S09	Individual Differences & Problem Solving
Jennifer Suk	S09	Cues to Solution & Insightful Restructuring

PROFESSIONAL REFERENCES

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