

RELATIONAL LANGUAGE AND INHIBITORY CONTROL IN THE DEVELOPMENT OF ANALOGICAL ABILITY

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ABSTRACT

This paper explores the role of relational language and inhibitory control in the development of children's analogical reasoning ability. In two experiments, children were asked to make a relational mapping between two pictures while ignoring a competing object match. Experiment 1 demonstrated that children were more successful at this task when they heard relational language. The performance of children who heard relational language was equally good with and without a distracting object match present. Experiment 2 asks whether children with better inhibitory control are also better at ignoring object matches when mapping relations. Results suggest that the impact of inhibitory control may differ across ages. Future work will address how the factors of relational language and inhibition interact in the development of analogical ability.

INTRODUCTION

Exploring the origins and development of analogical ability is crucial to understanding human cognition. Although children have demonstrated the ability to make and use analogies, their analogical competence falls short of what adults are capable of. For instance adults are better able to form analogies between complex relational structures (take, for example, the analogy between the solar system and the atom; Gentner & Toupin, 1986). Another striking difference between adults' and children's performance on analogical tasks is children's focus on objects and object properties over relations (Blades &

Cooke, 1994; Gentner & Toupin, 1986; Gentner & Rattermann, 1991). The transition from reliance on objects to relations has been termed the *relational shift* (Gentner, 1988).

What contributes to the development of children's analogical abilities, especially to the shift in focus from objects to relations? Traditionally, proposals of analogical development have fallen under two broad categories: *domain knowledge* approaches and *maturational constraints* approaches. *Domain knowledge* approaches emphasize the importance of children's conceptual repertoires in their ability to reason analogically. These theories suggest that children's ability to reason analogically increases as they accrue knowledge about a particular domain and its relations (Gentner, 1988; Gentner & Rattermann, 1991; Goswami & Brown, 1989; Rattermann & Gentner, 1998; Vosniadou, 1989). Children are capable of noticing and utilizing relational similarity when they are familiar with the relations of interest, but not when they have limited knowledge of the relevant relations. In contrast, *maturational constraints* approaches view age-related cognitive capacity as the key component underlying the development of children's analogical ability, emphasizing limitations in factors like children's working memory capacity (Halford, 1993), inhibitory control (Richland, Morrison, & Holyoak, 2006), and cognitive flexibility (Jacques & Zelazo, 2005).

In reality, both domain knowledge and maturational constraints must interact to influence analogical development. Richland, Morrison, and Holyoak (2006), using a mapping task adapted from Markman and Gentner (1993),

investigated 3- to 14-year-olds' ability to reason analogically when knowledge of the relevant relations was held constant. They showed children pairs of pictures depicting familiar relations (e.g. *chasing*) and asked children to find a corresponding object in the second picture that went with an object in the first picture. If children are reasoning analogically, they should select the second object based on its role in the relational structure. Richland et al. varied the complexity of the relations and the presence of a distracting object match¹ and found that although children at all age groups were familiar with the relations being tested (they succeeded on pairs without complex relations and with no object distractors), children's performance on the complex items and items with object distractors continued to improve until 14 years. Richland et al. argued from these results that knowledge accretion alone is not enough to account for the development of analogical ability. They attributed the remaining gains in performance to maturational factors, such as increases in working memory capacity and inhibitory control. Specifically, they proposed that increased working memory allowed older children to reason about more complex relations and that greater inhibitory control allowed older children to ignore compelling object matches in favor of appropriate relational matches.

Richland et al.'s (2006) proposal is consistent with data showing that the pre-frontal cortex (PFC), which is important for working memory and executive functions, including inhibition, is critical for relational reasoning (Krawczyk et al., 2008; Morrison et al., 2004; Viskontas, Morrison, Holyoak, Hummel, & Knowlton, 2004; Waltz, Lau, Grewal, & Holyoak, 2000). Developmentally, the PFC is

¹ In Richland et al.'s studies, the distracting object was present in the second picture but was not part of the main relational structure. In contrast, objects in Markman and Gentner's studies were always *cross-mapped*. That is, the object participated in the main relational structure of the second picture, but in a different role.

late to mature (Diamond, 2002). However, the relationship between these fundamental cognitive capacities and the ability to reason analogically has not been directly assessed in children. Thus, one goal of this research is to directly investigate the role of one proposed factor, inhibition, on children's ability to match relational structure while ignoring object matches.

A second goal of the present paper is to examine the role that relational language plays in children's analogical ability. Relational language is a representational tool that can help children focus on common relations and align two structures (Gentner & Rattermann, 1991). Loewenstein and Gentner (2005) found, for example, that aligning two three-tiered boxes in order to find a hidden object was difficult for young children. The task was even more challenging when distinct objects were placed at each location in the two boxes in such a way that corresponding objects were not in corresponding locations (the objects were *cross-mapped*). However, when the locations of the boxes were described with spatial language (e.g. *on, in, under* or *top, middle, bottom*), children were able to successfully align the two boxes and find the hidden toy.

As in Markman and Gentner's and Richland et al.'s studies, the present studies asked children to view pairs of scenes with familiar relations and to select an object from a target picture that corresponded with a particular object from the base picture. In Experiment 1, we manipulated whether children heard relational language to describe the pictures. Given previous research suggesting that relational language enhances children's analogical abilities, we expected that children who heard relational language would outperform children who heard neutral language. In Experiment 2, we asked whether children's inhibitory control predicted performance on the same analogical mapping task used in Experiment 1. Inhibition

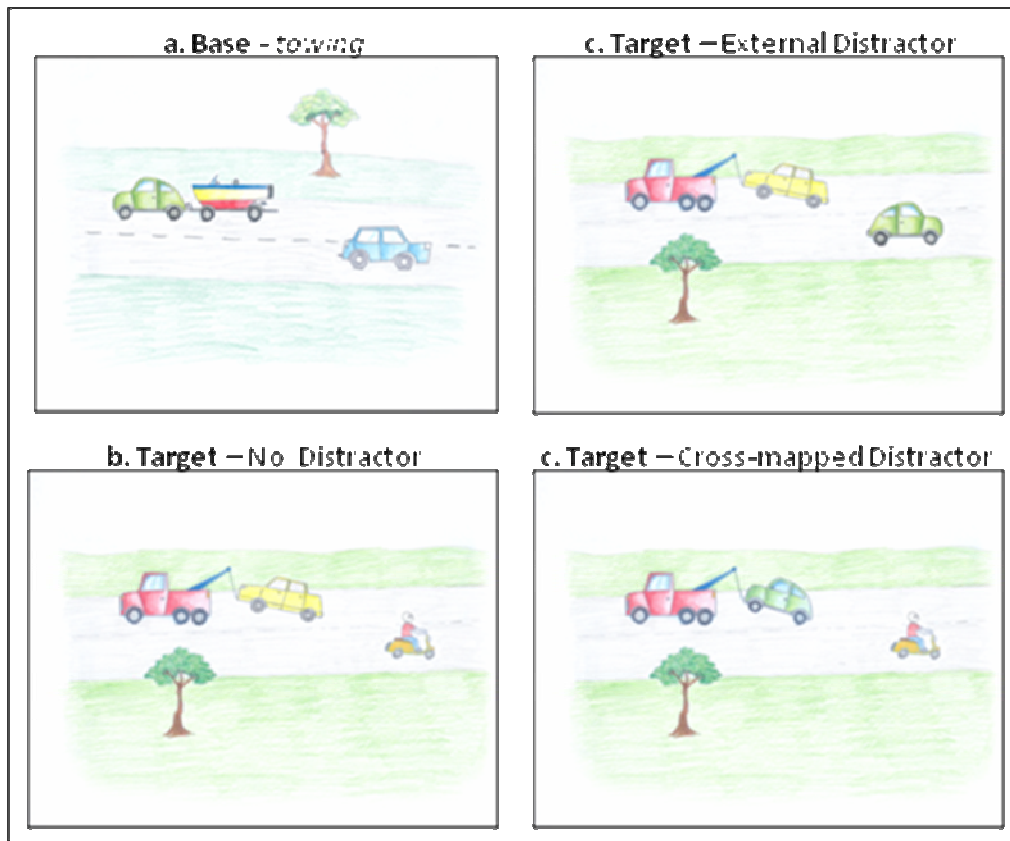


Figure 1. Sample stimuli pictures from analogical mapping task used in Experiments 1 and 2.

was assessed using the Day-Night Stroop Task, developed by Gerstadt, Hong, and Diamond (1994).

EXPERIMENT 1

Method

Twenty-four 3½-year-olds (ages 40-47, $M = 43.89$ months) and 21 5½-year-olds (ages 62-66, $M = 64.18$) participated in this study. Two additional 3½-year-olds refused to participate. All but four children participated in the lab at Northwestern University. The other four children (all 5½-year-olds) were tested individually at a local preschool.

Children viewed pairs of scenes depicting

familiar relations (e.g. *towing*) and were asked to select an object from the target picture that corresponded with the actor (the “doer” of the action) in the base picture. Age and Language Type (relational or neutral) served as between-subject factors. Because previous studies have not been consistent in the type of object match distractors used (for instance, Markman & Gentner, 1993, and Gentner & Toupin, 1986, used cross-mapped distractors, whereas Richland et al., 2006, used object distractors that were external to the main relational structure), the type of object distractor present for each pair of pictures was also manipulated as a within-subjects factor (Figure 1). Three Pair Types were used: (1) cross-mapped pairs, in which the object distractor participated in the

same relation in the target picture as in the base picture (e.g. *towing*), but in a different role (e.g. *towee* versus *tower*) (Figure 1d), (2) external distractor pairs, in which the distractor did not participate in the target relation, but was present in the target picture (Figure 1c), and (3) no-distractor pairs, in which no object distractor was present in the target picture (Figure 1b). Children saw a total of nine experimental picture pairs (three of each distractor type), each exemplifying a different relation (e.g. *towing*). The type of pair seen with each relation was counterbalanced across participants. In addition to the nine experimental trials, children also saw three practice trials, one of each pair type, for a total of twelve picture pairs.

On each trial, the experimenter began by laying down the first pair of practice pictures, with the base above the target, and saying:

“These two pictures have a pattern in them. It’s the same pattern, but it looks different in the two pictures. Let me show you what I mean. In this top picture, there’s a boy holding a dog. See that? And in the bottom picture, there’s an elephant holding a cat. See? So in both of these pictures, someone is holding something. That’s the pattern. Now, do you see this one [pointing to boy in top picture] right here? What does this one go with in the bottom picture? What’s in the same part of the pattern?”

On practice trials, children were given feedback about the correct (i.e. relational) answer, and incorrect practice trials were repeated. All children first saw the no distractor practice trial, followed by the external distractor practice trial, followed by the cross-mapped distractor practice trial.

Practice trials were followed by the nine experimental trials. On experimental trials, the experimenter did not ask for or give descriptions of the base and target pictures. Rather, the experimenter only asked what “goes with this one” in the target picture. Children in the Relational Language condition heard a relational description of the actor in the base (e.g. “Do you see this one that’s *towing*? What does this one go with in the bottom picture?”).

Children in the Neutral Language condition heard a neutral description of the actor (e.g. “Do you see this one? What does this one go with in the bottom picture?”). Children were given no feedback on experimental trials.

Results and Discussion

As predicted, children who heard relational language chose the relational match more often than those who did not. This was confirmed by a 2(Age) x 2(Language Type) x 3(Pair Type) repeated measures ANOVA over children’s relational responses, where Age and Language Type were between-subjects factors (Figure 2). Main effects of Age, $F(1,43) = 11.79, p < .01$, and Language Type, $F(1,43) = 13.06, p < .01$, were significant. The 5½-year-olds chose the relational match significantly more often than the 3½-year-olds, and children who heard relational language chose the relational match significantly more often than those who did not.

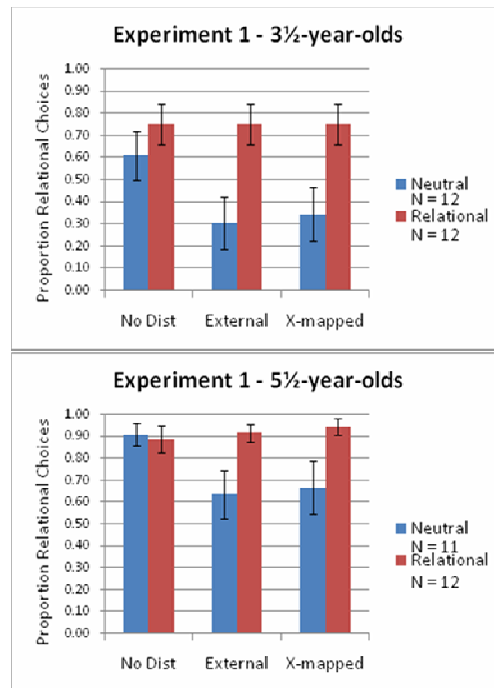


Figure 2. Proportion correct relational choices for each pair type in Experiment 1.

A main effect of Pair Type was also significant, $F(2,86) = 3.92, p < .05$. Children chose the relational match significantly more often when there was no distracting object match present.

The main effects of Pair Type and Language Type are best understood in light of their interaction, $F(2,86) = 5.22, p < .01$. Children who heard relational language chose the relational match as frequently on trials with a distractor (external or cross-mapped) as on those with no distractor. In contrast, children who heard neutral language chose the relational match significantly more frequently when there was no distractor than with either external or cross-mapped distractors (both Bonferronis, $p < .01$). Performance on the external and cross-mapped trials did not differ significantly. The three-way interaction with Age was not significant, suggesting that a similar pattern was found for both age groups.

In Experiment 1, as predicted, relational language helped children to select the appropriate relational match and ignore tempting object matches. In fact, children were just as accurate on distractor trials as on no-distractor trials when they heard relational language, suggesting that relational language helped children focus on the relational matches rather than on the competing object matches. Again, given how tempting young children find object matches, the fact that hearing relational language boosted their performance to levels equal to those where no object match was present is quite remarkable. It is also interesting that external distractors and cross-mapped distractors were equally disruptive to children's performance in the neutral language condition. The fact that children showed similar performance whether or not the object match participated in the relevant relation suggests that children may not be attending to the relation at all when an object match is present.

In Experiment 2, we sought to explore the relationship between inhibitory control and children's analogical ability. Richland et al. (2006) proposed that when children were familiar with the relevant relations, increased inhibitory control was responsible for the im-

provements in analogical mapping ability seen with age, specifically the ability to focus on relational similarity over object similarity. However, previous work has not directly assessed the relationship between inhibition and analogical ability in children. Thus in Experiment 2, we related performance on a measure of inhibitory control, the Day-Night Stroop Task (Gerstadt et al., 1994), with performance on the analogical mapping task from Experiment 1. To more closely monitor age-related changes in inhibitory control and analogical ability, we also included 4½-year-olds in addition to 3½- and 5½-year-olds in Experiment 2.

EXPERIMENT 2

Method

Sixteen 3½-year-olds, 12 4½-year-olds, and 14 5½-year-olds participated. Three 3½-year-olds and one 5½-year-old were excluded due to failure to meet the training criterion of the Day-Night Stroop task, outlined below. Two additional 3½-year-olds did not finish the Stroop task, and one 5½-year-old was excluded due to experimenter error, leaving 11 3½-year-olds (ages 39-44 months, $M = 41.55$), 12 4½-year-olds (ages 51-56, $M = 53.58$), and 12 5½-year-olds (ages 63-68 months, $M = 64.60$) in the present analysis. All children were tested individually, either at their preschool or in the lab at Northwestern University.

Children completed both the Day-Night Stroop Task and the mapping task from Experiment 1. Order of administration was counterbalanced across participants. The procedures of the analogical mapping task are identical to those in Experiment 1 except that all children heard neutral language throughout the task.

The Day-Night Stroop task was administered as described in Gerstadt et al. (1994). In the Stroop task, children are shown a series of pictures of suns and moons and must say "night" or "day," respectively, to each picture. To illustrate, when a child is shown a picture of a sun, they must say "night." This requires

that the child inhibit a more fluent, consistent response (i.e. “day”) in favor of the correct, mis-matched response.

To introduce the Stroop task, children were shown one of each kind of card (moon and sun, Figure 3) and told that they should say “day” when they see a moon card and say “night” when they see a sun card. After this introduction, the experimenter began showing children the cards one at a time. Children were given two chances to correctly respond to one of each kind of card. If they were unable to respond appropriately to both the sun and moon on the first try, they were reminded of the rules of the game. If they were unable to respond correctly on the second try, their data were excluded from further analysis. If they were able to respond appropriately on the first or second try, the correct responses counted as the first two of sixteen trials. Including the first two cards, the order of administration was as follows for all children: n, d, d, n, d, n, n, d, d, n, d, n, n, d, n, d. Children received no feedback on the final fourteen trials. Children who were reluctant to verbalize their responses were prompted only with, “What do you say for this one?” – the words “day” and “night” were not used during the test trials. If children changed their answer or provided two responses, only their last answer was counted.

Results and Discussion

To examine children’s performance on the mapping task, their number of relational responses were entered into a 3(Age) x 2(Test Order) x 3(Pair Type) mixed measures ANOVA, with Pair Type as a within subjects factor. A main effect of Age was found, $F(2,28) = 8.05, p < .01$. Three-and-a-half year olds ($M = 4.36, SD = 1.91$) selected relational matches significantly less often than either the 4½-year-olds ($M = 7.00, SD = 2.17$) or 5½-year-olds ($M = 7.10, SD = 1.79$) (both Bonferronis, $p < .01$), who selected relational matches equally often. A main effect of Test Order was marginally significant, $F(1,28) = 3.00, p = .09$, such that children who participated in the mapping task before the Stroop

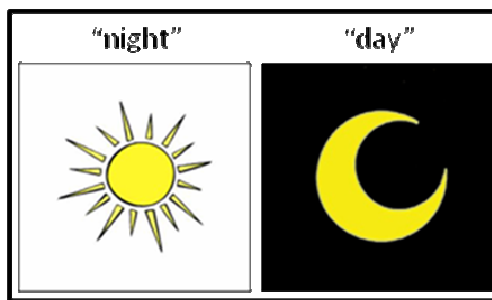


Figure 3. Sun and Moon pictures from Day-Night Stroop Task used in Experiment 2.

task ($M = 6.65, SD = 2.15$) made more relational choices than children who participated after the Stroop task ($M = 5.62, SD = 2.42$). This difference in performance is not surprising, given that children in the latter case had already completed one task and may have been fatigued. Importantly, Test Order did not interact significantly with any other factors.

No other main effects or interactions were significant. Of particular note is that the expected effect of Pair Type found in Experiment 1, with more relational responses found on trials with no distractors present in the target picture, was not found (No distractors: $M = 2.18, SD = 0.92$; External distractors: $M = 2.06, SD = 0.90$; Cross-mapped distractors: $M = 1.91, SD = 1.10$). This is surprising given the robust effect of object similarity on children’s ability to reason analogically that has been found in previous work. It is possible that the effect would emerge given more participants.

Children’s performance on the Day-Night Stroop Task was evaluated by entering children’s number correct (out of 16) into a 3(Age) x 2(Test Order) univariate ANOVA. Neither of the main effects or the interaction were significant. Although a main effect of Age on this measure of inhibition was expected, it is possible that the effect may have been significant had more participants been included.

Finally, to evaluate the relationship between children’s inhibitory capacity and analogical mapping ability, children’s Day-Night Stroop scores and relational responses from the mapping task were correlated separately for

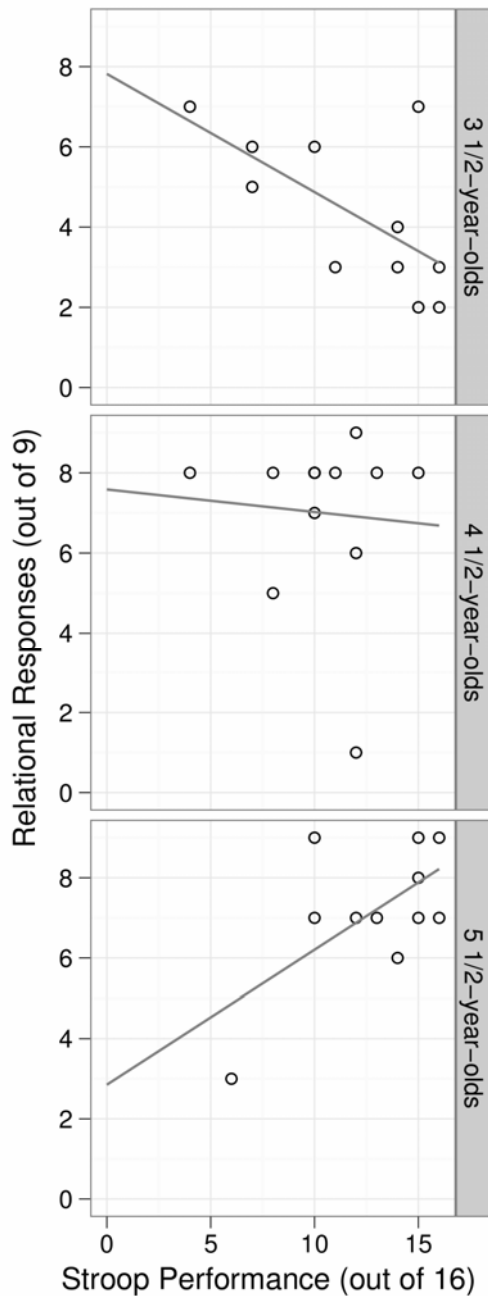


Figure 4. Relational responses plotted by Stroop performance in Experiment 2..

each age group (depicted in Figure 4). For the

youngest age group, children’s performance on the Stroop task *negatively* correlated with relational responding on the mapping task, $r = -.65$, $p < .05$. For 4½-year-olds, Stroop performance and relational responding were not significantly correlated. For 5½-year-olds, these factors were positively correlated, $r = .61$, $p < .05$. Although visual inspection of the data suggest that this effect in the 5½-year-olds may be driven by an outlier, the correlation remains marginally significant when this data point is excluded, $r = .39$, $p = .07$.

Data from Experiment 2 suggest that the relationship between inhibition (as measured by the Day-Night Stroop task) and performance on the analogical mapping task may differ across age groups. However, these results should be interpreted with caution, given that several expected results – namely an effect of an object distractor on children’s mapping abilities and age-related improvements in inhibition, measured by the Stroop task – were not found. It is possible that with additional participants, these expected results would emerge.

From this study, it appears that the relationship between inhibitory control and analogical mapping ability may not be as straightforward as initially suggested. Richland et al. (2006) postulated that beyond children’s knowledge of the relevant relation, increases in inhibition accounted for children’s ability to ignore compelling object matches in favor of relational matches during an analogical mapping task. It is unclear why the relationship between inhibition and analogical mapping ability should differ across age groups in the manner seen here, and further work is needed to confirm and explore it.

One explanation for the present data are that the Day-Night Stroop task did not measure inhibitory control as intended. The task includes semantic factors (e.g. the meanings of “day” and “night”) which may open the door to a variety of strategies that might be used differently by different age groups. For instance, older children may have approached the Stroop task as an “opposites” game (e.g. “it’s not the one I think it is, it’s the opposite”), which would strongly draw on inhibi-

tory control, whereas the younger children in this study may have used a different strategy. Many of the younger children especially, for example, simply alternated responses (“day” “night” “day” “night”...), which in most cases led to a Stroop score of about 11 out of 16. However, alternating responses might actually reflect low inhibitory control, if children got into a habit of alternating answers on the first few trials. Future work will need to use different measures of inhibitory capacity to explore this issue.

Another possibility is that younger children, despite the practice trials and feedback, believed the game was about finding another of the same kind (e.g. another green car), rather than the one in the same relational role. In this case, children with high inhibition who were looking for an object match might be very good at selecting an object match, and thus would show very few relational matches.

GENERAL DISCUSSION

This paper discusses the impact of two factors that have been suggested to play a role in the development of analogical ability: relational language and inhibitory control. Experiment 1 demonstrated that children who heard relational language were better able to solve an analogical mapping task than children who heard neutral language. Experiment 2 suggests that the relationship between inhibition and analogical ability may not be straightforward. It is possible that the nature of this relationship changes with age, though further work is needed to confirm this pattern.

Independently, relational language and maturational gains in cognitive capacity – like inhibition – surely have roles to play in the development of analogical ability. Future work should also consider how these factors interact in shaping children’s mapping abilities. Gentner and colleagues (Gentner, 2003; Gentner & Clement, 1988) have emphasized that relational language may help children by selecting among several possible conceptualizations, or by highlighting the common relations, so that the child is better able to attend to the common

structure. For example, rather than representing an object as a *car*, hearing a relational label *tower* might suggest focusing on the towing relation and on the role of the car within that structure. Relational language might also help to make representations more efficient, which may impose fewer processing demands on children’s working memory (Morrison & Cho, 2007). Language may also promote cognitive flexibility, an important factor involved in executive function (Jacques & Zelazo, 2005).

Planning is underway to expand the research presented here to examine the interplay between inhibition, relational language, and analogical ability. Using the design of Experiment 2, we will manipulate whether children hear relational language during the analogical mapping task, as we did in Experiment 1. This research will serve as a first step at exploring the relationship between the various factors considered important for analogical development.

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