DESCRIPTIVE LANGUAGE AND CHILDREN'S SPATIAL MEMORY

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by

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ABSTRACT

Across three studies, we explored the relationship between language about object features and children's spatial memory. Five- to 8-year-olds constructed a 14-piece spatial configuration and then reconstructed the configuration from memory. In Study 1, children in a labeling condition (*n* = 23) labeled the shapes and colors of the configuration before the reconstruction task, whereas children in a no-labeling condition (*n* = 24) pointed to each piece in the configuration. Contrary to our hypothesis, children in the labeling condition did not remember the configuration better than children in the no-labeling condition. In Study 2, 57 children narrated while constructing the spatial configuration, and their use of shape and color words predicted their memory for the shapes and colors of the individual pieces in the configuration. In Study 3, children labeled only the shapes (*n* = 16), only the colors (*n* = 16), or both the shapes and colors (*n* = 15) of the spatial configuration. A no-labeling condition pointed to each piece in the configuration (*n* = 11). Children who labeled color remembered the configuration better than children who did not label the configuration. These studies offer insights into how language supports children's spatial memory. We discuss the implications of these findings as well as the new questions they engender.

Keywords: spatial cognition, spatial language, object features, spatial memory

BIOGRAPHICAL SKETCH

Ashley Ransom was born and grew up in Van Buren, Arkansas. She received her B.A. in psychology from Hendrix College in 2007. She then went on to the University of Arkansas where she received her M.A. in experimental psychology in 2010. After receiving her M.A., she taught kindergarten in South Korea. Upon returning to the United States, she worked as a research assistant at the University of Chicago. She started as a graduate student in Human Development at Cornell University in 2016. During her time at Cornell, she has conducted research on early spatial development and children's beliefs about language and accents.

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Descriptive Language and Children's Spatial Memory

We live in a world of objects, and these objects have multiple properties: Each object has a size, texture, luminance, mass, shape, and color. Every day we process thousands of object properties without realizing it. Object properties, and our ability to remember them, are such a fundamental part of our daily experience that we rarely stop to consider the role they play in spatial cognition. Because object properties are so ubiquitous, it is worth considering how they affect our memory for the objects we encounter. Here we investigate how descriptive language (specifically, talk about shape and color) relates to children's spatial memory for an arrangement of objects.

Spatial memory allows us to remember the objects around us — both their location and their descriptive properties — and is only one of the many spatial skills that let us interact seamlessly with our physical environment. Without these skills we would be unable to complete even simple tasks such as locating our keys or remembering the way to a friend's house. In addition, spatial skills are imperative for academic achievement — especially in the areas of science, technology, engineering, and mathematics (collectively called the STEM fields). Spatial skills form the foundation for early math and science learning and later success in the STEM fields. This connection between spatial ability and academic achievement begins in infancy. Lauer and Lourenco (2016) found that infants' performance on a mental rotation change detection task at 6- to 13-months predicted their math ability at 4-years. Verdine et al. (2014) found that three-year-olds' performance on a spatial assembly task predicted their current math ability, and, remarkably, Cheng and Mix (2014) found that six to eight-year-olds showed improvement on missing number problems after a single mental rotation training session.

The association between math and spatial ability does not stop in childhood; it continues into adolescence and adulthood. Mental rotation ability mediates gender differences on high school students' math performance on standardized tests (Casey, Nuttall, & Pezaris, 1997), and spatial skills in adolescence predict success in the STEM fields years later (Shea, Lubinski, Benbow, 2001; Wai, Lubinski, & Benbow, 2009). Spatial skills also play important roles in a variety of educational and occupational settings such as art, chemistry, biology, and geometry. The ability to imagine objects from multiple perspectives is beneficial for a diverse set of activities from sculpting to visualizing chemical molecules in three-dimensions.

One particular type of spatial skill, spatial memory, can be broadly divided into two categories (Uttal et al., 2013) — navigational memory and object memory. Navigational memory allows us to traverse through space: We can remember the route between our home and work as well as the layout of our neighborhood and house. In contrast, object memory allows us to remember individual objects, the location of objects in space and the relationships among objects. Imagine that I want to describe the location of a book in my office. Before I can provide this information, I must recall the arrangement of objects in my office. I must remember that the book is on the right side of my desk near a pile of papers and behind several pencils. As another example, imagine how difficult it would be to cook a meal if you could not remember the location of ingredients in your kitchen. Although we may not be aware of it, situations such as these happen throughout our day and, without the ability to recognize and remember objects, our lives would be incredibly difficult.

Descriptive language may be one way to enhance our spatial memory — especially our memory for the objects around us. Although few studies have looked directly at the relationship between descriptive language and spatial memory, there is an abundance of research demonstrating a relationship between language and spatial ability. There is clear evidence that early language input is related to children's spatial development. For instance, children's exposure to and production of spatial words early in life predicts their spatial abilities in the preschool years (Pruden, Levine, and Huttenlocher, 2011). Laboratory studies show that exposure to spatial language (e.g., "in the middle") before or during spatial tasks improves children's performance on these tasks. Spatial language exposure can improve children's performance on mapping tasks (Loewenstein & Gentner, 2005), feature-binding tasks (Dessalegn & Landau, 2008/2013), and the formation of spatial categories (Casasola, Bhagwat, & Burke, 2009; Casasola, 2005). More naturalistic studies have also found a relationship between spatial language and spatial ability. Casasola, Wei, Suh, Donskoy, and Ransom (under second review) found that children's exposure to spatial language over several weeks led to improvements in spatial skills. Furthermore, a number of studies have shown that children who have larger receptive or expressive spatial vocabularies perform better on spatial tasks (Ankowski, Thom, Sandhofer, & Blaisdell, 2012; Balcomb, Newcombe, & Ferrara, 2011; Hermer-Vasquez, Spelke, & Katnelson, 1999; Miller, Vlach, & Simmering, 2016; Piccardi, Palermo, Bocchi, Guariglia, & D'Amico, 2015; Simms & Gentner, 2008; Pruden, Levine, & Huttenlocher, 2011; Gentner, Özyürek, Gürcanli, & Goldin-Meadow, 2013).

While there is an obvious connection between language and spatial ability, the majority of work in this area has focused on language about the relationships among objects (Miller, Patterson, & Simmering, 2016; Dessalegn & Landau, 2008/2013; Casasola, Bhagwat, & Burke, 2009; Casasola, 2005; Loewenstein & Gentner, 2005). However, descriptive language about object properties may also play an essential role in spatial thinking. When we talk about the physical world, we use multiple types of language. We talk about individual objects, object properties, and the relationships among objects. Consider the famous quote by Lao Tzu, “The journey of a thousand miles begins with a single step.” In order to express its sentiment, this sentence refers to objects (“journey”, “miles”, “step”), object properties (“thousand”, “single”), and the relationship between objects (“begins with”). This is merely one example of the diverse language that we are exposed to daily. By focusing on relational language (see citations above), we are missing part of the picture. Multiple types of language are used to describe the physical world; therefore, we should explore the relationship between multiple types of language and our thinking about the physical world.

One way descriptive language could boost spatial memory is by strengthening object encoding. A commonly studied spatial ability is mental rotation, and mental rotation requires you to form a mental representation of an object before mentally manipulating it. Talking about object features (such as the size, shape, and color of the object) may improve encoding of the object; thus, making it easier to rotate. Similarly, descriptive speech could scaffold our memory for object location. In Loewenstein and Gentner’s (2005) mapping study, they asked children to find a “winner” in a box with three levels. Before the search task, children were asked to place the winner on one level of the box. Phrases such as “Can you put the winner *on* the box?” improved children’s performance. It is also possible, though, that descriptive language could further scaffold children’s performance on this task. A phrase such as “Can you put the *small* card on the *blue* box?” provides more information and might increase children’s encoding of the relevant spatial information.

There is empirical evidence that descriptive language can facilitate the encoding of visual information. Souza and Skóra (2017) asked adult participants to remember a series of colored dots. The participants then had to reproduce the sequence of dots using a continuous color wheel on a computer. Since the visual stimuli was a continuous variable, this measured participants' ability to encode the exact hue of each dot in the sequence. Participants who were allowed to label the colors of the dots as they were presented were more accurate on the memory test. Their color choices were closer to the true colors than participants who were not allowed to label the colors. Bernbach (1967) found a similar result in four and five-year-olds. Four and five-year-olds were asked to remember a series of colored cards, and children remembered the cards better when they could label the colors. These results demonstrate that talking about features can boost encoding of visual information.

There is also empirical evidence that talking about object features can improve children's performance on a spatial task. In a study by Rattermann and Gentner (1998), three- and four-year-olds watched an experimenter hide an object in one of three containers that increased in size. Children then had to find an object in a second set of containers that was in the same location as in the first set. Children performed at chance when the sets were different, but when the experimenter labeled the size of the containers ("tiny, little, big"), children's performance drastically improved. Thus, descriptive language can bolster spatial thinking by highlighting object properties.

In a longitudinal study, Pruden, Levine, and Huttenlocher (2011) measured parent and child speech at home when children were between 14 and 46 months and then assessed children's spatial skills at 54 months. They were specifically interested in parents' and children's production of descriptive spatial words — shape words (e.g., triangle), spatial dimension words (e.g., "big"), and spatial property words (e.g., "pointy"). They found that parental use of these words predicted children's production of these words and that child spatial language production mediated the relationship between spatial language exposure and children's performance on a mental transformation task and spatial analogies task. Casasola, Wei, Suh, Donskoy, & Ransom (under second revision) found that exposure to spatial language during multiple play sessions improved children's mental transformation and mental rotation skills from baseline to posttest. Furthermore, they found that, in addition to other types of spatial language (e.g., pattern words), exposure to these same three categories of spatial words — shape, spatial dimension, and spatial property words — predicted children's improvement. Since these categories of words are used to talk about object properties, these two studies offer further evidence that descriptive language can benefit children's spatial cognition.

The goal of the present studies was to explore the relationship between descriptive language and children's spatial memory. In these studies, we looked at a spatial object feature (shape) and a non-spatial object feature (color). By examining both types of object features, we can better understand the role that talking about object features plays in children's spatial memory. It may be that talking about object features only improves children's spatial memory when the language is spatial in nature — for instance, talking about shape or size. In contrast, it may be that talking about object features improves children's spatial memory regardless of the nature of the language. Non-spatial object features such as color may boost children's visual encoding to the same degree as spatial features. Miller, Patterson, and Simmering (2016) found that children were especially attentive to color during a spatial task. When they asked children to describe the location of a toy, they found that children used more color words than relational words (e.g., "between") even though color was irrelevant to the task. Children's attention may naturally be drawn to certain non-spatial object features (such as color), and careful attention to these features may scaffold visual encoding even though the features are not spatial in nature.

Although it is not a spatial feature, color provides supplementary information about an object and is a powerful cue that bolsters object recognition. Throughout our lives, we learn to associate certain shapes with certain colors (Chao, Haxby, & Martin, 1999); we learn that banana-shaped objects are yellow and tree-shaped objects are green and brown. These strong associations allow us to encode and process information about objects more quickly. This is especially true of objects with predictable colors; we can classify and recognize objects faster when they are colored typically than when they are colored atypically (Proverbio, Burco, Zotto, & Zani, 2004; Tanaka & Presnell, 1999; Vernon & Lloyd-Jones, 2003; Lloyd-Jones & Nakabayashi, 2009; Humphrey, Goodale, Jakobson, & Servos, 1994, Bramão, Inácio, Faísca, Reis, & Petersson, 2010). Furthermore, we can name the color of objects faster when the color and object match in typicality (Naor-Raz, Tarr, & Kersten, 2003).

In contrast, humans rely on shape to identify objects. This begins around 2-years when children start to develop a "shape bias" in which they focus on shape when learning new words and categorizing objects (Landau, Smith, & Jones, 1988). Children prefer to categorize novel objects by shape over other features (Vlach, 2016; Landau, Smith, & Jones, 1988; Graham, Williams, & Huber, 1999; Landau, Smith, & Jones, 1998) and learn to name shapes much earlier than colors (Modreski & Goss, 1969). Even adults remember shape better than other object characteristics (Vlach, 2016) and are slower to recognize previously seen objects when the shape of the object has changed but not when the color of the object has changed (Cave, Bost, & Cobb, 1996).

Across three studies, we examined the relationship between talking about shape and color and children's memory for a spatial configuration. A spatial configuration is a collection of objects that are arranged to form a larger picture. For example, think of how a collection of puzzle pieces are arranged to form a coherent scene. The spatial configuration in our studies formed a rocket and was made out of 14 wooden pieces that varied in shape and color. After constructing the rocket, children were asked to reconstruct the rocket from memory and were then given a recognition memory test in which they had to choose the pieces they remembered from the rocket. We chose this spatial memory task because it allowed us to examine children's memory for the internal arrangement of objects in the rocket as well as for the individual objects in the rocket. Additionally, shape and color were especially relevant object features for this particular task since the rocket was made out of pieces in five shapes and five colors. Lastly, we wanted to use an arrangement that formed a concrete object. Mandler and Parker (1976) asked college students to recreate an arrangement of objects. Sometimes the objects followed a schema (e.g., a school scene with desks, students, and a teacher), and sometimes the objects did not follow a schema (e.g., the desks, students, and teachers were placed in random locations on a page). Participants were better at recreating the schematic scene than the non-schematic scene. The participants in our studies were between 5 and 8-years-old. Since our spatial configuration formed a rocket, children could use this information strategically during the reconstruction memory task. This made the difficulty of the task more appropriate for school-aged children than if we had used a spatial configuration that formed an abstract shape. Additionally, we chose to test school-aged children because, if shape and color language assists spatial thinking, this would be an easy educational strategy to implement.

In two studies we examined the effect of labeling shape and color on children's memory for the spatial configuration. Specifically, we examined the effect of asking children to label the shapes and colors of the configuration on their memory for the configuration. Rather than focusing on exposure to spatial language, our studies focused on children's production of spatial language. In another study, we looked at children's spontaneous speech when constructing the rocket. This allowed us to see what features children naturally attend to when interacting with an arrangement of objects and how this attention facilitates their memory for the objects. We explored how children's use of shape and color words predicted their memory for the shapes and colors of the spatial configuration. By examining children's production of descriptive language in two contexts — an experimental context and a naturalistic context — we were able to study the distinction between elicited speech and spontaneous speech. It may be that one type of speech is more beneficial than the other. Allowing children to spontaneously produce language gives them the freedom to focus on the features they find most useful and so may be more beneficial than focusing their attention on certain object features. In contrast, by asking children to label shape and color, the experimenter focused their attention on the features most relevant to the spatial task.

Study 1

The goal of Study 1 was to examine the effect of labeling shape and color on children's spatial memory. We asked children to construct a spatial configuration that formed a rocket. We then randomly assigned them to one of two conditions — a labeling condition in which they labeled the rocket shapes and colors or a no-labeling condition in which they pointed to each rocket piece. Next, we measured their memory for the rocket with two tasks. One task measured their ability to reconstruct the rocket from memory; the other measured their ability to recognize the rocket pieces. We hypothesized that labeling the rocket shapes and colors would improve children's memory for the rocket on both tasks. Souza and Skóra (2017) found that asking participants to label colors improved their encoding for the colors. Similarly, we expected that asking children to label the rocket shapes and colors would improve their memory for these rocket features. Second, we hypothesized that children would remember shape better than color when reconstructing the rocket from memory. Shape plays a central role in children's object identification and categorization (e.g., Landau, Smith, & Jones, 1988). Since children were asked to construct a configuration that formed an identifiable object (a rocket), we expected them to use shape to guide their construction. Third, we hypothesized that children would recognize the rocket colors better than the rocket shapes. Although shape is important for object identification, color plays an important role in object recognition (e.g., Tanaka & Presnell, 1999). Additionally, children are especially attentive to color (Miller, Patterson, & Simmering, 2016). Fourth, we hypothesized that performance on the two memory tasks would be correlated. The rocket is formed from individual pieces; children who are better at remembering the relationships among these pieces should also be better at recognizing the individual pieces.

Study 1 Method

Participants

Forty-eight five- to eight-year-olds participated in the study at an elementary school. One child was excluded from the sample for not completing both memory tasks. The final sample was 47 children (M_{age} = 7.14 years, SD = 0.69) with 20 females. Twenty-six children were White (62%), 7 were Hispanic/Latino, 2 were Asian, 1 was Black, and 7 were multiracial. Fifteen children had a parent with a college degree (32%). We were missing demographic information for five children. All children were fluent English speakers.

Procedure

The first task was a card sort task that measured shape bias; this was an exploratory measured that did not yield any relevant results. The second task was a shape vocabulary task. This was not a comprehensive measure of shape vocabulary; it only measured children's memory for six shapes. The last tasks were a mental rotation task and a mental transformation task; only half of the children completed these two tasks. We will not discuss these tasks further, but a complete description is available at osf.io/9zejt/.

Children were tested individually in a quiet room away from their classroom and completed the tasks in the order listed.

Reconstruction memory. The reconstruction memory task measured children's ability to reconstruct the rocket from memory. We used a Djeco® magnet set that contained a magnetic, white surface and 43 wooden magnets in six shapes (arc, circle, rectangle, semicircle, square, triangle) and five colors (blue, green, orange, red, yellow) that varied in size. We also used a small card depicting the rocket that came with the magnet set. The rocket consisted of 14 pieces in five shapes (triangle, rectangle, square, arc, semicircle) and five colors (orange, red, blue, yellow, green) (See Figure 1).

The experimenter asked the child to construct the rocket using the card as a guide. Afterward, the experimenter checked that the child's rocket was identical to the card. If the child made mistakes, the experimenter and child fixed them together.

Next, children were randomly assigned to one of two conditions — a labeling condition (n = 24) or a no-labeling condition (n = 23). In the labeling condition, the experimenter asked the child to name the shape and color of each rocket piece as she pointed to it. If a child did not know the name of a shape, the experimenter named the shape and asked the child to repeat it. In the no-labeling condition, the experimenter and child pointed to each piece of the rocket together. We did this so that children in both conditions attended to every piece. The experimenter always started at the top of the rocket and moved down from left to right.

After the rocket construction, the experimenter turned the rocket card upside down and deconstructed the rocket. She then said, "Do you think you can rebuild the rocket without looking at the card? It's okay if you don't remember everything. Do the best that you can, and you can take as much time as you want." If the child asked for help, the experimenter gave a generic answer such as, "I think you're doing a good job" or "Do you remember anything else?" This was a surprise memory test; children were not told in advance that they would reconstruct the rocket.

Once the child finished, the experimenter checked that the child's rocket was identical to the card. If the child made mistakes, the experimenter and child fixed them together. We did this so that children saw the correct rocket before the recognition memory task.

Recognition memory. The recognition memory task measured children's ability to recognize the rocket pieces. We used four laminated cards that showed three colorful shapes (See Figure 2). On each card, one shape was part of the rocket and two shapes were not part of the rocket.

In four shape recognition trials, the cards showed three different shapes in the same color (e.g., red semicircle, red arc, red triangle). Children had to use shape to differentiate the pieces. In four color recognition trials, the cards showed three identical shapes in different colors (e.g., blue square, green square, red square). Children had to use color to differentiate the pieces. For each trial, the child was asked to choose the shape that was part of the rocket. The order of the shape and color recognition trials was counterbalanced.

After the shape and color recognition trials, children completed four mixed recognition trials. The cards showed three different shapes in three different colors (e.g., red triangle, orange semicircle, green rectangle). These trials did not yield any relevant results and were not included in Studies 2 and 3. We will not discuss these trials further, but a complete description is available at osf.io/9zejt/.

Study 1 Results

Reconstruction Coding

We coded the accuracy of children's rocket reconstructions. The first author and a research assistant coded the reconstructions separately then compared the coding. Any discrepancies were resolved through a conversation. A complete description of our coding scheme is available online at osf.io/ghrwu.

We created four variables to measure children's reconstruction memory; these are described below. See Figures 3 and 4 for the frequency of these errors across studies.

Total reconstruction score. The total reconstruction score measured how many pieces of the rocket reconstruction were correct. A piece was correct if it was the correct shape and color in the correct location. There were 14 pieces in the rocket, so the scores could range from 0 (no correct pieces) to 14 (all correct pieces) with higher scores indicating better memory

Shape reconstruction errors. Shape reconstruction errors measured children's memory for the rocket shapes. A piece was a shape reconstruction error if it was the wrong shape but the correct color and in the correct location. More shape reconstruction errors indicated worse shape memory.

Only two children out of 47 made a shape reconstruction error in Study 1. In Studies 2 and 3, no child made a shape reconstruction error. Therefore, we will rarely consider this variable in our analyses.

Shape-only reconstruction score. We created another variable to measure children's memory for the rocket shapes because shape reconstruction errors were so rare. The shape-only reconstruction score measured how many pieces of the rocket reconstruction were correct, ignoring color. A piece was correct if it was the correct shape and in the correct location. There were 14 pieces in the rocket, so the scores could range from 0 (no correct pieces) to 14 (all correct pieces) with higher scores indicating better shape memory.

Color reconstruction errors. Color reconstruction errors measured children's memory for the rocket colors. A piece was a color reconstruction error if it was the wrong color but the correct shape and in the correct location. More color reconstruction errors indicated worse color memory.

Age and Gender

There was a significant correlation between age and total reconstruction score, $r(45) = .35$, $p = .02$, and age and shape-only reconstruction score, $r(45) = .38$, $p = .009$. Older children did significantly better on the rocket reconstruction task than younger children.

Girls ($M = 3.55$, $SD = 0.83$) did significantly better on the color recognition trials than boys ($M = 2.89$, $SD = 1.01$), $t(45) = 2.39$, $p = .02$, 95% CI[-1.22, -0.10].

Reconstruction Memory

See Figure 5 for condition differences in total and shape-only reconstruction scores.

We conducted an analysis of covariance (ANCOVA) with condition as a between-subjects variable, age as a covariate, and total reconstruction score as the dependent variable. We included age as a covariate because it was correlated with total reconstruction score. There was a significant effect of age, $F(2, 44) = 6.58$, $p = .02$, but there was no significant effect of condition, $F(2, 44) = 2.68$, $p = .11$, $R^2 = .17$. Children in the labeling condition ($M = 8.17$, $SD = 3.03$) did not have higher total reconstruction scores than children in the no-labeling condition ($M = 9.83$, $SD = 2.79$).

We conducted an ANCOVA with condition as a between-subjects variable, age as a covariate, and shape-only reconstruction scores as the dependent variable. We included age as a covariate because it was correlated with shape-only reconstruction scores. There was a significant effect of age, $F(2, 44) = 5.95$, $p = .02$, and a significant effect of condition, $F(2, 44) = 4.85$, $p = .03$, $R^2 = .23$, but the effect of condition was in the opposite direction expected. Children in the labeling condition (*M* = 10.08, *SD* = 2.80) had lower shape-only reconstruction scores than children in the no-labeling condition (*M* = 11.87, *SD* = 2.01).

We conducted an independent samples t-test with condition as a between-subjects variable and color reconstruction errors as the dependent variable. Children in the labeling condition (*M* = 1.91, *SD* = 1.50) did not make fewer color reconstruction errors than children in the no-labeling condition (*M* = 2.04, *SD* = 1.82), $t(45) = 0.26$, $p = .80$, 95% CI [-1.06, 0.85].

We conducted a paired samples t-test to compare shape and color reconstruction errors. Children made significantly fewer shape reconstruction errors (*M* = 0.04, *SD* = 0.20) than color reconstruction errors (*M* = 1.98, *SD* = 1.65), $t(46) = 8.00$, $p < .001$, 95% CI[1.45, 2.42].

Recognition Memory

We measured shape recognition memory by summing the number of shape recognition trials that children got correct. This score could range from 0 to 4 with a higher score indicating better shape recognition memory. We conducted an independent samples t-test with condition as a between-subjects variable and shape recognition memory as the dependent variable. Children in the labeling condition (*M* = 2.17, *SD* = 1.24) did not have better shape recognition memory than children in the no-labeling condition (*M* = 2.57, *SD* = 1.50), $t(45) = 0.99$, $p = .33$, 95% CI[-1.21, 0.41].

We measured color recognition memory by summing the number of color recognition trials that children got correct. This score could range from 0 to 4 with a higher score indicating better color recognition memory. We conducted an independent samples t-test with condition as a between-subjects variable and color recognition memory as the dependent variable. Children in the labeling condition (M = 3.29, SD = 1.24) did not have better color recognition memory than children in the no-labeling condition (M = 3.04, SD = 1.50), $t(45) = 0.86$, $p = .39$, 95% CI[-0.33, 0.83].

We conducted a paired samples t-test to compare shape and color recognition memory. Children had significantly better color recognition memory (M = 3.17, SD = 0.99) than shape recognition memory (M = 2.36, SD = 1.37), $t(46) = 4.65$, $p < .001$, 95% CI[0.46, 1.16].

Relationship Between Reconstruction and Recognition Memory

We measured total recognition memory by summing the number of shape and color recognition trials that children got correct. This score could range from 0 to 8 with a higher score indicating better recognition memory. There was a significant correlation between total reconstruction score and total recognition memory, $r(45) = .38$, $p = .009$. Children with higher total reconstruction scores had better recognition memory. Additionally, there was a significant correlation between color reconstruction errors and color recognition memory, $r(45) = -.32$, $p = .03$. Children with better color recognition memory made fewer color reconstruction errors.

Study 1 Discussion

The goal of Study 1 was to test the effect of labeling shape and color on children's memory for a spatial configuration — specifically their memory for the relationships among the pieces (reconstruction memory) as well as their memory for the individual pieces (recognition memory). Contrary to our hypothesis, labeling the rocket shapes and colors did not improve children's memory for the rocket. There was no difference between the labeling and no-labeling conditions for total reconstruction score, color reconstruction errors, shape recognition memory, or color recognition memory. Surprisingly, there was a difference between the labeling and no-labeling conditions for shape-only reconstruction score, but this was in the opposite direction hypothesized. Children who labeled the rocket shapes and colors showed worse memory than children who did not label the rocket pieces.

One explanation is that labeling both shape and color provided too much information for children. Perhaps the labeling increased children's cognitive load and interfered with their encoding of the rocket. We address this possibility in Study 3 in which we compare labeling only shape, labeling only color, and labeling both shape and color. Another possibility is that children do not naturally attend to shape and color during this spatial task and so labeling was not helpful for encoding. We address this possibility in Study 2 in which we examine children's spontaneous speech when constructing the rocket and how this relates to their memory for the rocket.

Our other hypotheses for Study 1 were supported. Children made fewer shape than color errors when reconstructing the rocket; this supports our hypothesis that shape is a stronger retrieval cue than color during reconstruction. Additionally, children performed better on the color recognition trials than the shape recognition trials; this supports our hypothesis that color is more helpful for object recognition than shape.

Study 2

The goal of Study 2 was to examine the relationship between children's spontaneous references to shape and color while constructing the rocket and their memory for the shapes and colors of the rocket. We asked children to narrate while constructing the rocket and coded the language they produced. We then examined the relationship between their speech and their memory for the rocket. We hypothesized that children's spontaneous use of shape words would predict their memory for the rocket shapes. We reasoned that children who attended to shape would be better at remembering shape. Similarly, we hypothesized that children's spontaneous use of color words would predict their memory for the rocket colors. We reasoned that children who attended to color would be better at remembering color. Children's attention to these features should strengthen their encoding of these features thus leading to improved memory. We also hypothesized that children would make fewer shape reconstruction errors than color reconstruction errors and that children would do better on the color recognition memory trials than the shape recognition memory trials. These hypotheses were identical to our hypotheses in Study 1, and we expected to replicate our findings.

Study 2 Method

Pre-registration

This study was preregistered through the Open Science Framework. The preregistration is available at osf.io/ghrwu.

Participants

Sixty-five five- to eight-year-olds participated in the study at a university lab. Six children were excluded from the sample due to experimenter error (n = 5), failure to follow instructions (n = 1), and being three standard deviations below the mean on a mental transformation task (n = 2). The final sample was 57 children (M_{age} = 7.33 years, SD = 1.06) with 32 females. Forty-nine children were White (86%), and eight were multiracial. Fifty-two children had a parent with a college degree (91%). All children were fluent English speakers.

We pre-registered a sample of 58 six to eight-year-olds, but we extended the age range to include 5-year-olds to match our sample in Study 1. Additionally, we unintentionally recruited two extra children.

Procedure

In addition to the tasks reported below, children completed a shape sort task (different from the card sort task in Study 1) to measure shape bias. This was the first task that children completed and did not yield any relevant results. Children also completed a mental transformation task before the working memory task. This did not yield any relevant results. We will not discuss either of these tasks further, but a complete description is available at osf.io/ghrwu.

Children were tested individually in a quiet room and completed the tasks in the order listed.

Origami. The origami task was a warm-up task. We wanted to accustom children to talking aloud since they would be asked to narrate during the rocket construction task. Additionally, this helped children become comfortable with the experimenter and the testing environment. We used two instructional booklets for the origami task. One booklet demonstrated how to make an origami pig; the other demonstrated how to make an origami whale. Each page had a picture depicting one step of the process. The booklets did not include any words.

First, the experimenter and child created an origami whale. The experimenter pointed to each picture in the instructional booklet and gave simple verbal instructions (e.g., "we fold the top of the paper down"). The instructions were the same for all children. Next, the experimenter and child created an origami pig, but this time the experimenter asked the child to explain the instructions in the booklet. If the child became stuck on a step, then the experimenter provided help before letting the child continue.

Reconstruction memory. The reconstruction memory task was identical to the reconstruction task in Study 1 except that, instead of a labeling manipulation, children were asked to narrate while constructing the rocket. Before asking the child to construct the rocket, the experimenter said, "Can you tell me what you're doing while you build this?" If the child was hesitant to speak, the experimenter prompted with simple questions such as, "What are you doing now?", but the experimenter spoke as little as possible.

Recognition memory*.* We made three changes to the recognition memory task from Study 1. First, we removed the mixed-recognition trials. Second, we added an extra trial to the shape recognition and color recognition trials so that there were five trials that tested shape recognition memory and five trials that tested color recognition memory. Third, we administered the task on an iPad via Qualtrics. The order of the shape recognition trials and color recognition trials was counterbalanced.

NIH Toolbox List Sorting Working Memory Test. This assessed children's working memory and was administered through the NIH Toolbox app on an iPad.

In the first section, children saw a series of animals or food and had to repeat the items (from memory) from smallest to biggest. The section ended once a child missed two items in a row. In the second section, children saw a series of animals and food together. They had to first list the foods in size-order and then the animals in size-order. Again, the section ended when a child missed two items in a row.

Study 2 Results

Language Coding

We audio recorded and transcribed children's speech while constructing the rocket. A research assistant who had not transcribed the sessions read the transcripts while listening to the recordings. She highlighted any discrepancies between the transcripts and the recordings, and the first author resolved the discrepancies.

We used the computer program CLAN (Computerized Language ANalysis) to calculate the number of total words, shape words, and color words that the child and the experimenter produced. A list of the shape and color words we used is available online at osf.io/ghrwu. See Table 1 for the frequency of these words.

Gender

There was a significant gender difference on the working memory test. Girls' percentile rank (M = 62.55, SD = 22.22) was significantly higher than boys' (M = 48.00, SD = 23.69), $t(52)$ = 2.31, p = .03, 95% CI[-27.12, -1.93].

We did not conduct age correlations since age was included in our linear regression models.

Linear Regression Models

We conducted a series of linear regressions. For each model, we ensured that the residuals were normally distributed. We also checked for interactions between age and shape words and age and color words. These interactions were not significant (p > .05) for any of the models. All of our regression models included the same five predictors — age, working memory score, the number of shape words produced, the number of color words produced, and the total number of words produced.

Reconstruction Memory

Although we did not pre-register the analyses, we examined total reconstruction scores and shape-only reconstruction scores as exploratory analyses. The linear regression model with total reconstruction score as the dependent variable was not significant, $p >$ .05. The linear regression model with shape-only reconstruction score as the dependent variable was marginally significant, $R^2 = .19$, $F(5, 47) = 2.23$, $p = .07$, but shape words (b = .16, 95% CI [.03, .29], $p = .02$) was a significant predictor of shape-only reconstruction score. Children who used more shape words had higher shape-only reconstruction scores.

The linear regression model with color reconstruction errors as the dependent variable was not significant, $R^2 = .15$, $F(5, 47) = 1.60$, $p = .18$, but shape words, ($b = .13$, 95% CI [.03, .24], $p = .02$), was a significant predictor of color reconstruction errors. Children who produced more shape words made more color reconstruction errors. Color words (b = -.10, 95% CI [-.20, .005], $p = .06$) was a marginally significant predictor of color reconstruction errors.

As an exploratory analysis, we conducted the linear regression model for color reconstruction errors without age or working memory since these were not significant predictors. A linear regression model with total words, shape words, and color words was marginally significant, $R^2 = .14$, $F(3, 53) = 2.79$, $p =.05$. Now color words was a significant predictor of color reconstruction errors ($b = -.10$, 95% CI [-0.19, -0.004], $p = .04$), and shape words remained a significant predictor. Children who produced more color words made fewer color reconstruction errors.

We conducted a paired samples t-test comparing shape reconstruction errors and color reconstruction errors. Children made significantly fewer shape reconstruction errors

(M= 0, SD = 0) than color reconstruction errors (M = 1.96, SD = 1.81), t = -8.19, 95% CI [-2.45, -1.48], $p < .001$ when reconstructing the rocket pattern. This replicated our finding from Study 1.

Recognition Memory

As in Study 1, we tested shape recognition memory by summing the number of shape recognition trials that children got correct. This score could range from 0 to 5 with a higher score indicating better shape recognition memory. The linear regression model with shape recognition score as the dependent variable was significant, R^2 = .25, F(5, 47) = 3.16, p = .02. Age (b = .33, 95% CI = [.06, .60], p = .02) and shape words (b = -.07, 95% CI [-.13, -.01], p = .02) were significant predictors of shape recognition. Older children did better on the shape recognition trials than younger children, and children who produced more shape words did worse on the shape recognition trials than children who produced fewer shape words. This result was in the opposite direction expected.

As in Study 1, we tested color recognition memory by summing the number of color recognition trials that children got correct. This score could range from 0 to 5 with a higher score indicating better color recognition memory. The linear regression model with color recognition score as the dependent variable was not significant, R^2 = .03, F(5, 47) = 0.29, p = .91, nor were there any significant predictors.

We conducted a paired samples t-test comparing color recognition memory and shape recognition memory. There was no significant difference between color recognition memory (M = 4.04, SD = 1.03) and shape recognition memory (M = 4.11, SD = 1.11), t = -0.39, 95% CI [-0.43, 0.29], p = .70. This did not replicate our finding from Study 1.

Study 2 Discussion

The goal of Study 2 was to examine the relationship between children's spontaneous references to shape and color and their memory for the rocket. Overall, there was support for our hypotheses that shape words would predict memory for the shapes of the rocket, and color words would predict memory for the colors of the rocket.

Shape words predicted better shape-only reconstruction scores, which was a measure of children's memory for the rocket, ignoring color. Children who produced more shape words remembered the layout of the shapes of the rocket better. However, shape words did not predict total reconstruction scores, which measured children's overall memory for the rocket including color. Shape words actually predicted worse memory for the colors of the rocket. Children who focused on shape may have focused less on color, which was detrimental to their total reconstruction scores.

Surprisingly, shape words predicted worse shape recognition memory. Children who focused on shape may have been more attentive to the overall layout of the rocket and less attentive to the individual pieces of the rocket. Talking about shape may scaffold memory for object relationships but not individual objects.

Color words predicted better color memory during the reconstruction tasks. Children who used more color words remembered the colors of the rocket better. However, color words did not predict better color recognition memory. There were no significant predictors of color memory. Also, we did not replicate our findings from Study 1 in which color recognition memory was better than shape recognition memory, and girls had better color recognition memory than boys.

Interestingly, total words did not predict any variables. Thus, it was not the amount of language that children produced that mattered — rather it was the type of language that children produced that mattered. This suggests that speaking in general is not enough to facilitate spatial memory; rather descriptive language in particular may facilitate spatial memory.

Study 2 offered clear evidence that shape and color can support children's memory for a spatial configuration. In Study 3, we addressed another possible explanation for our findings in Study 1 by manipulating which features of the rocket that children labeled.

Study 3

In Study 1, children who labeled the rocket shapes and colors did not remember the spatial configuration better than children in the no-labeling condition. In fact, children in the no-labeling condition had higher shape-only reconstruction scores than children in the labeling condition. In Study 3, we explored a possible explanation: Children in the labeling condition were overwhelmed. Labeling both shape and color may have been too much information for children to process. We addressed this possibility in Study 3 by adding two new labeling conditions: labeling only the colors of the rocket and labeling only the shapes of the rocket. We hypothesized that children who labeled only color would remember the rocket colors better than children in the other conditions but would remember the rocket shapes worse than children in the other conditions. We reasoned that labeling color would make this property more prominent but simultaneously make shape less prominent. In study 2 we found that children's use of color words predicted better memory for the colors of the rocket but worse memory for the shapes of the rocket. Similarly, we hypothesized that children who labeled only shape would remember the rocket shapes better than children in the other conditions but would remember the rocket colors worse than children in the other conditions. We reasoned that labeling shape would make this property more prominent but simultaneously make color less prominent. Third, we hypothesized that children who labeled both shape and color would have worse memory for the rocket than children in the other conditions. We reasoned that labeling both the shapes and colors of the rocket overwhelmed children in Study 1; thus labeling only one feature would be better than labeling two features. Additionally, we expected to replicate our finding from Study 1 in which children who labeled both shape and color did worse than children in the no-labeling condition.

Study 3 Method

Pre-registration

This study was preregistered through the Open Science Framework. The preregistration is available at osf.io/9zejt.

Participants

Seventy-two five- to eight-year-olds participated in the study: 21 at a university alumni event, 48 at a children's science museum, and 3 at a university lab. Fourteen children were excluded from the sample due to not finishing the study (n = 6), missing age information (n = 2), previous participation in a similar study (n = 2), experimenter error (n = 2), and developmental delay (n = 2). The final sample was 58 children (M_{age} = 6.89 years, SD = 1.13) with 30 females. Thirty-eight children were White (68%), 4 were Asian American, 1 was Hispanic/Latino, 1 was Black, and 12 were multiracial. Fifty children had a parent with a college degree (89%). We were missing demographic information for two children. All children were fluent English speakers.

We pre-registered a sample of 64 children. Data collection is ongoing.

Procedure

As in Studies 1 and 2, children completed a mental transformation task. However, we did not have any hypotheses regarding this task, and we did not analyze the data. Children completed this task at the end of the study, and we will not discuss it further.

All children were tested individually; the children at the alumni event and science museum were tested away from the activities. Children completed the tasks in the order listed.

Reconstruction memory. The reconstruction memory task was the same as in Study 1 except that there were two new labeling conditions. After constructing the rocket, children were randomly assigned to one of four conditions — a shape-labeling condition (*n* = 16), a color-labeling condition (*n* = 16), a both-labeling condition (*n* = 15), or a no-labeling condition (*n* = 11).

In the shape-labeling condition, the experimenter asked the child to name the shape of each piece. If a child did not know the name of a shape, the experimenter labeled the shape and asked the child to repeat the name of the shape. In the color-labeling condition, the experimenter asked the child to name the color of each piece. In the both-labeling condition, the experimenter asked the child to name the shape and color of each piece. In the no-labeling condition, the experimenter and child pointed to each piece of the rocket together.

As a note, the both-labeling condition was identical to the labeling-condition in Study 1, and the no-labeling condition was identical to the no-labeling condition in Study 1.

Recognition memory. This was identical to the recognition memory task in Study 2.

Study 3 Results

Age and Gender

There was a significant correlation between age and color recognition memory, $r(56) = .32$, $p = .02$. Older children had better color recognition memory than younger children.

There were no significant gender differences. However, color recognition memory was marginally significant with girls ($M = 3.87$, $SD = 0.97$) outperforming boys ($M = 3.36$, $SD = 1.06$), $t(56) = 1.91$, $p = .06$, 95% CI[-1.05, 0.03]. This came close to replicating our finding in Study 1 in which girls had better color recognition memory than boys.

Reconstruction Memory

See Figure 6 for condition differences in total and shape-only reconstruction scores.

We conducted an ANOVA with condition as a between-subjects factor and total reconstruction score as the dependent variable. There was a significant difference among the conditions for total reconstruction score, $F(3, 54) = 3.45$, $p = .02$. Using Tukey's HSD, we found that children in the color-labeling condition ($M = 9.69$, $SD = 2.80$) had significantly higher total reconstruction scores than children in the no-labeling condition ($M = 6.00$, $SD = 4.22$), $p = .02$, 95% CI[-6.83, -0.54].

We conducted an ANOVA with condition as a between-subjects factor and shape-only reconstruction score as the dependent variable. There was a significant difference among the conditions for shape-only reconstruction scores, $F(3, 54) = 4.40$, $p = .007$. Using Tukey's HSD, we found that children in the color-labeling condition ($M = 11.00$, $SD = 2.80$)

had significantly higher shape-only reconstruction scores than children in the no-labeling condition (M = 7.27, SD = 4.22), p = .01, 95% CI[-6.77, 0.68]. Additionally, children in the both-labeling condition (M = 10.93, SD = 2.05) had significantly higher shape-only reconstruction scores than children in the no-labeling condition, p = .01, 95% CI[-6.75, -0.57].

We conducted a one-way analysis of variance (ANOVA) with condition as a between-subjects factor and color reconstruction errors as the dependent variable. There was no significant effect of condition, F(3, 54) = 1.52, p = .22.

Recognition Memory

We conducted an ANOVA with condition as a between-subjects factor and shape recognition memory as the dependent variable. There was no effect of condition for shape recognition memory, F (3, 54) = 0.35, p = .80.

We conducted a one-way ANCOVA with condition as a between-subjects factor, age as a covariate, and color recognition memory as the dependent variable. We included age as a covariate because it was correlated with color recognition memory. There was a significant effect of age, F(4, 53) = 6.46, p = .02, but there was no effect of condition, F(4, 53) = 0.94, p = .43, R^2 = .15.

Study 3 Discussion

The goal of Study 3 was to examine the possibility that labeling both shape and color overwhelmed children in Study 1, and so they did worse on the rocket reconstruction task compared to children in the no-labeling condition. If this is true, then children who labeled only the rocket shapes or only the rocket colors in Study 3, should remember the rocket better than children who labeled both the shapes and colors.

This hypothesis was not supported. Children in the shape-labeling and color-labeling conditions did not outperform children in the both-labeling condition on any measure. We only found three condition differences. Children in the color-labeling condition remembered the rocket better than children in the no-labeling condition — this was true for both total reconstruction scores and shape-only reconstruction scores. Additionally, children in the both-labeling condition remembered the rocket better than children in the no-labeling condition — this was true for shape-only reconstruction scores. This is the opposite pattern of results from Study 1, and we discuss possible reasons for this in the general discussion. There was no effect of condition for shape or color recognition memory.

General Discussion

We explored whether and how descriptive language scaffolds children's spatial memory. Descriptive language may scaffold spatial memory by helping children form mental images of objects and thus encode them more efficiently. In three studies, we explored how talking about two object properties — shape and color — affected and related to children's performance on two spatial memory tasks.

In Study 1, children labeled the shapes and colors of a spatial configuration that formed a rocket and then reconstructed the rocket from memory. Unexpectedly, children who labeled the rocket shapes and colors had worse memory for the rocket than children who did not label the shapes and colors. In studies 2 and 3, we explored possible explanations for this finding.

In Study 2, we examined the possibility that children did not naturally attend to shape and color during this particular spatial task. We asked children to narrate while constructing the rocket then looked at how their language production predicted their memory for the rocket. If children are not attending to shape and color during the rocket construction task, then children's talk about shape and color should not predict their performance. If, however, children are attending to these object properties, then children's talk about shape and color should predict their memory for the rocket shapes and colors. This hypothesis was supported. Children's spontaneous references to shape and color while constructing the rocket predicted their memory for shape and color during the reconstruction task. Children who used more color words when constructing the rocket had better memory for the rocket colors. Similarly, children who used more shape words when constructing the rocket had better memory for the layout of the rocket shapes.

In Study 3, we explored the possibility that labeling both shape *and* color was detrimental to children's memory. We reasoned that children in Study 1 might have found it overwhelming to label both object properties, which impeded their ability to accurately encode the rocket. To test this hypothesis, we asked children to label only the rocket shapes, only the rocket colors, or both the rocket shapes and colors. We compared these three labeling conditions to a no-labeling control condition. Children who only labeled the rocket colors remembered the rocket better than children who did not label the rocket pieces. Furthermore, children who labeled both the rocket shapes and colors remembered the layout of the rocket shapes better than children who did not label the rocket pieces. In Study 1 we found the opposite pattern of results: Children who labeled the rocket shapes and colors had worse memory for the rocket than children who did not label the rocket pieces.

There are several possibilities for the discrepancy between Study 1 and Study 3. First, our results in Study 3 may be the result of a type I error due to the small sample size. In Study 1, 24 children labeled both shape and color, and 23 children did not label the rocket pieces. In contrast, in Study 3, 15 children labeled both shape and color, and 11 children did not label the rocket pieces. The no-labeling control condition in Study 3 was half the size of the no-labeling control condition in Study 1. Thus, we should be careful interpreting the results of Study 3 in light of the small sample size.

These divergent results may also be due to demographic differences in our samples. The children in Study 1 were, on average, from lower-income households with less parental education than the children in Study 3. In Study 3, 89% of children had a parent with a college degree. In contrast, only 32% of children in Study 1 had a parent with a college degree. If children in Study 3 could label the shapes more easily than children in Study 1, this labeling might not have obstructed their ability to encode the configuration. Two of the shapes in our spatial configuration, semicircle and arc, were particularly difficult for children to label. Children in Study 3 may have been more familiar with these shapes and so found the labeling task less difficult. However, a replication with a comprehensive shape vocabulary measure is necessary if we want to truly understand these results.

Although the significant difference between the both-labeling condition and no-labeling condition in Study 3 was unexpected, it is still worth noting that children in the color-labeling condition remembered the rocket significantly better than children in the no-labeling condition. This was not in line with our hypothesis that labeling color would enhance memory for color and worsen memory for shape, but it does suggest that labeling color alone may be more useful to children then labeling shape alone. There was no difference between the no-labeling condition and the shape-labeling condition for any of our measures.

Additionally, labeling color alone may also be better than labeling both shape and color. Children who labeled both shape and color had significantly higher shape-only reconstruction scores than children in the no-labeling condition. In contrast, children who only labeled color had significantly higher shape-only reconstruction scores *and* total reconstruction scores than children in the no-labeling condition. The shape-only reconstruction score measured how well children remembered the spatial configuration, ignoring color. The total reconstruction score measured how well children remembered the spatial configuration, including color. Thus, the total reconstruction score was a stricter measure of spatial memory than the shape-only reconstruction score.

Our results from Study 3 offer some evidence that descriptive language can influence spatial memory but are difficult to interpret because of the conflicting results from Study 1. Our results from Study 2, however, provide clear evidence that descriptive language is associated with spatial cognition. When we asked children to narrate while constructing the rocket, we found that their spontaneous production of shape and color words predicted their memory for the rocket, particularly their performance on the reconstruction task.

Shape words were especially interesting because they predicted performance on several measures. First, children who produced more shape word had higher shape-only reconstruction scores, showing better memory for the layout of the rocket shapes. Shape words also predicted worse memory for the rocket colors. Children who produced more shape words made more color errors when reconstructing the rocket. It may be that some children focused on encoding the shapes of the configuration to the detriment of encoding the colors. In contrast, children who produced more color words made fewer color errors when reconstructing the rocket. Surprisingly, shape words predicted worse shape recognition memory. It may be that children who were very attentive to shape were more focused on the relationships among objects than on individual objects; thus they had better memory for the overall layout of the rocket configuration but worse memory for the individual shapes

Our understanding of how and when language supports children's spatial memory is invaluable because spatial skills are crucial for academic success. Research has established that language can enhance spatial performance (Miller, Patterson, & Simmering, 2016; Dessalegn & Landau 2008/2013; Loewenstein & Gentner, 2005; Casasola, Wei, Suh, Donskoy & Ransom (under second revision)), and our research contributes to this literature by showing a connection between children's spatial memory and production of descriptive language. Overall, our results offer support for the premise that talking about objects can enhance children's memory for objects. This may be especially important for fields that require accurate object encoding such as engineering. Still, future studies are necessary to completely understand these results and expand upon our findings.

First, we need to replicate the labeling manipulation from Study 1 with a larger sample size and a more comprehensive measure of spatial vocabulary. This would allow us to test the hypothesis that spatial vocabulary mediates the effect of the labeling manipulation. In particular, it would allow us to test the hypothesis that only children with strong spatial vocabularies can take advantage of the labeling manipulation.

Another future direction is to compare talking about object properties, such as shape and color, to talking about the relationships among objects. This would enable a direction comparison between descriptive and relational language. Although a strength of Study 2 was that it was conducted in a naturalistic manner, an experimental manipulation would allow us to draw more decisive conclusions. In a future study, we could ask children to describe the individual pieces of the configuration versus the relations among the pieces. In this way, we could manipulate the type of language children spontaneously produce without forced labeling.

Lastly, studies should further examine the advantages and disadvantages of labeling versus natural speech. It may be that descriptive language facilitates spatial thinking when children are allowed to speak naturally, but there is less of a benefit when an experimenter forces children to focus on particular object characteristics. Future studies could directly compare children's spatial memory for a spatial configuration after being allowed to speak freely during construction versus being asked to label certain object features.

These studies offer both new information and new questions about the way that language supports spatial cognition. We now know that children's talk about objects — specifically their talk about shape and color — is related to their spatial memory. However, it is unclear if the manner in which the language is elicited matters. Asking children to label objects may not be as useful as allowing them to spontaneously talk about objects. Additionally, children's spatial vocabulary may play a role in the usefulness of descriptive language. Nevertheless, these studies are the first steps towards a better understanding of the relationship between descriptive language and children's spatial memory and can be the impetus for further research on this topic.

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Appendix

Figure 1

Rocket spatial configuration that children constructed

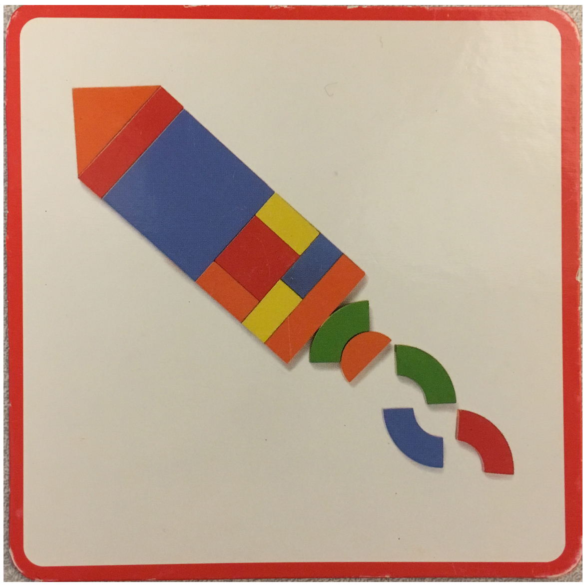

Figure 2

Shape recognition memory trial (left) and color recognition memory trial (right)

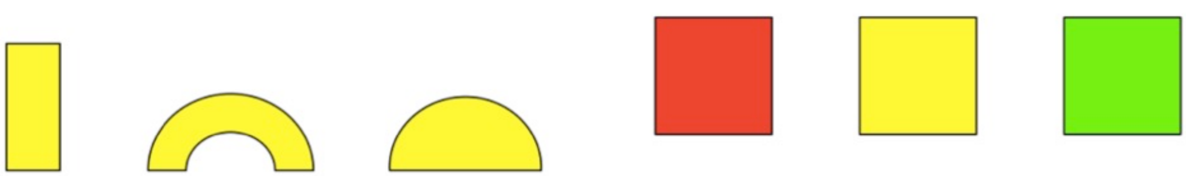

Figure 3

Average reconstruction scores in each study (with standard error)

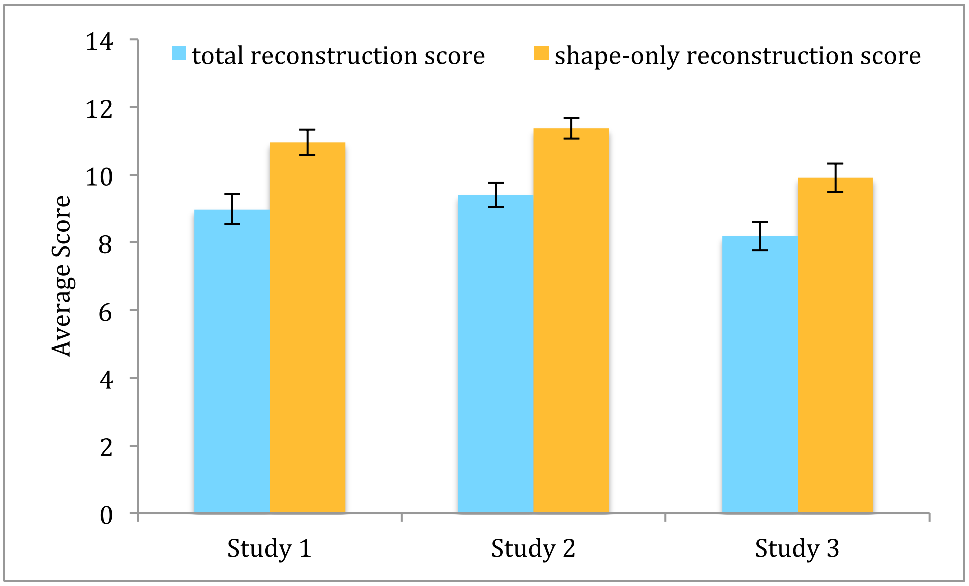

Figure 4

Average number of color reconstruction errors in each study (with standard error)

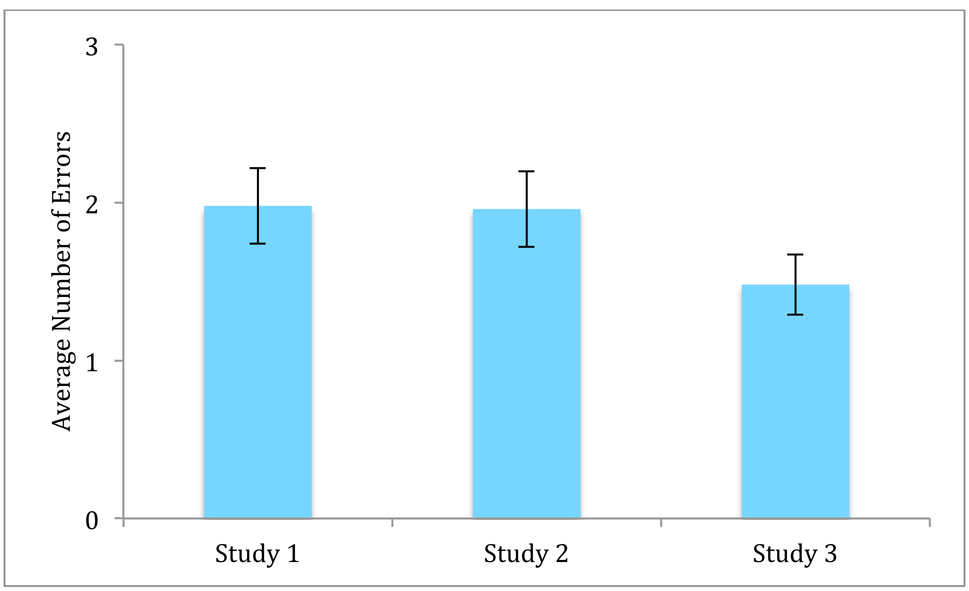

Figure 5

Average reconstruction scores in Study 1 (with standard error)

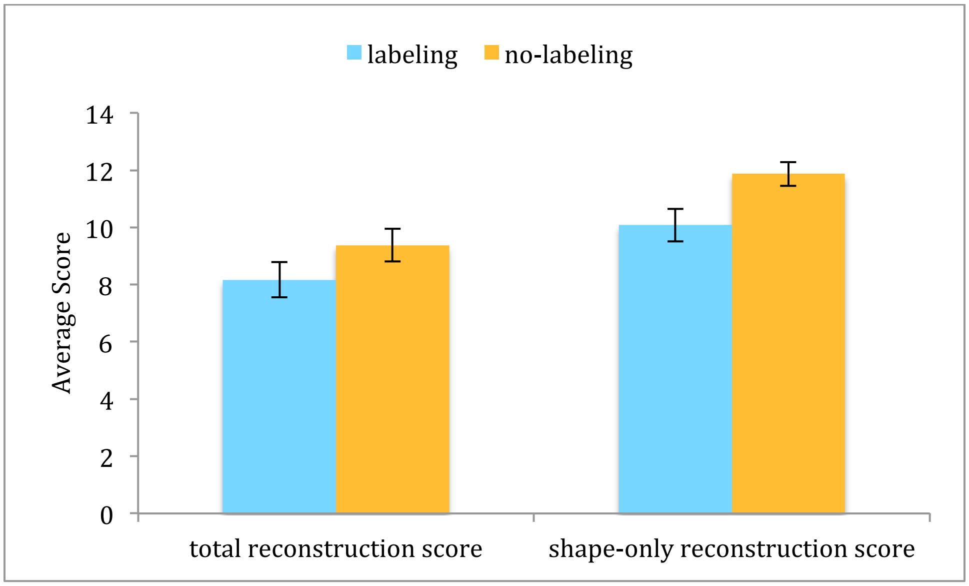

Figure 6

Average reconstruction scores in Study 3 (with standard error)

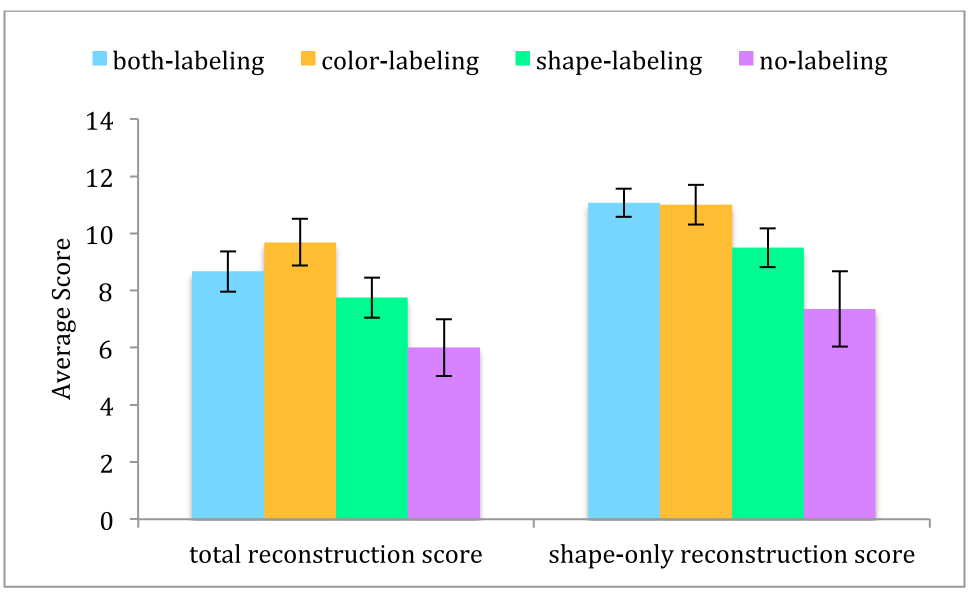

Table 1

Child Word Production During the Construction Task in Study 2

	Mean (SD)	Range	Median
Total words	134.05 (59.76)	39 - 321	130
Color words	10.05 (7.00)	0 -29	11
Shape words	6.77 (6.01)	0 - 24	5