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RUNNING HEAD: EFFECTS OF LANGUAGE ON CHILDREN'S NAVIGATION

Cognitive effects of language on human navigation

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Abstract

Language has been linked to spatial representation and behavior in humans, but the nature of this effect is debated. Here, we test whether simple verbal expressions improve 4-year-old children's performance in a disoriented search task in a small rectangular room with a single red landmark wall. Disoriented children's landmark-guided search for a hidden object was dramatically enhanced when the experimenter used certain verbal expressions to designate the landmark during the hiding event. Both a spatial expression ("I'm hiding the sticker at the red/white wall") and a non-spatial but task-relevant expression ("The red/white wall can help you get the sticker") enhanced children's search, relative to uncued controls. By contrast, a verbal expression that drew attention to the landmark in a task-irrelevant manner ("Look at this pretty red/white wall") produced no such enhancement. These findings provide further evidence that language changes spatial behavior in children and illuminate one mechanism through which language exerts its effect: by helping children understand the relevance of landmarks for encoding locations.

Keywords: spatial cognition, children, navigation, reorientation, landmark use, cognitive development, language

Navigating creatures use many types of information to represent their position and orientation in space, including self-generated movement, landmark objects, polarized light, and the overall layout of surrounding surfaces (Alerstam, 2006; Gallistel, 1990; Muheim, Phillips, & Åkesson, 2006). In humans, language has been linked to spatial representation and behavior, particularly in the use of landmarks (Hermer-Vasquez, Moffet, & Munkholm, 2001; Pyers, Shusterman, Senghas, Emmorey, & Spelke, 2010), but the role of language in human navigation is not clear. Effects of language on navigation might represent a subset of a broader class of experiences that could influence navigation through domain-general mechanisms, or such effects might be specific to the domain of language. In either case, the mechanisms through which language plays any role in spatial cognition have not been specified. Language may direct attention to, enhance memory for, or integrate distinct sources of information about the environment (e.g., Frank, Gibson, Fedorenko, & Everett, 2008; Landau & Lakusta, 2009; Spelke & Tsivkin, 2001; Waxman & Markow, 1995; Haun, Rapold, Call, Janzen, & Levinson, 2006). Furthermore, these possibilities are not mutually exclusive, and language could have multiple effects on representations of the environment. Indeed, a recent study demonstrated that mastery of distinct aspects of spatial language is related to performance on different spatial tasks (Pyers et al., 2010). Here, we investigate specific roles that language could play in the development of spatial cognition. We systematically vary the verbal descriptions that children hear during a disoriented search task and test which features of language affect their navigation.

Use of Landmarks and Geometry in Navigation

Previous research shows that children reliably use certain geometric properties of an environment, like relative wall lengths, to find a location after becoming disoriented (reviewed in

Cheng & Newcombe, 2005; Hermer & Spelke, 1994, 1996; Learmonth, Nadel, & Newcombe, 2002; Learmonth, Newcombe, & Huttenlocher, 2001). Under many conditions, children fail to use other visual features of the room to guide their search. For instance, children's search is not guided by the distinction between a red wall and a white wall, or between alternating red and blue walls, in a square room (Lourenco & Huttenlocher, 2007; Wang, Hermer, & Spelke, 1999), or by a colored patch of fabric on one side of a cylindrical room (Gouteux & Spelke, 2001, although the color difference is salient to them and accessible in other types of tasks. In contrast, two recent studies have reported above-chance performance in disoriented search tasks that required young children to integrate the relation between a hidden object and two walls differing in brightness in a square room (Nardini, Atkinson, & Burgess, 2008), an octagonal room with one colored wall (Newcombe, Ratliff, Shallcross, & Twyman, 2009), or a cylindrical room containing a distinctively patterned quilt on one side (Newcombe et al., 2009). A different study, however, reported failure in a cylindrical room with two dark patches on a white background (Lee & Spelke, 2010). The reasons for the discrepant results are not clear, but it should be noted that even the successes are just barely (though significantly) above chance, leaving room for language to enhance children's performance in all the above situations.

In animals, landmark use is influenced by rearing experience (Brown, Spetch, & Hurd, 2007), training (Gouteux, Thinus-Blanc, & Vauclair, 2001; Sovrano, Bisazza, & Vallortigara, 2002), and motivation (Dudchenko, Goodridge, Seiterle, & Taube, 1997). Children's use of landmark features in a reorientation task can be influenced by the nature of the features, the size of the enclosure, and previous experience. A series of studies has shown that children use landmarks much more readily when the arena is four times as large as the 4' x 6' (1.2 m x 1.8 m) room used in Hermer and Spelke's original (1994) study (Learmonth et al., 2002). In adults, different performance patterns emerge in small and larger arenas, both in a cue-conflict paradigm (Ratliff & Newcombe, 2008a) and in a dual-task paradigm with verbal shadowing (Ratliff & Newcombe, 2008b), with larger rooms consistently evoking more reliance on visual landmarks and smaller rooms evoking more reliance on geometric properties. This difference has primarily been used to argue against the hypothesis that an encapsulated 'geometric module' selectively uses geometric information, and ignores featural information, in reorientation tasks (Learmonth et al., 2002; Ratliff & Newcombe, 2008a; Learmonth, Newcombe, Sheridan, & Jones, 2008; Twyman & Newcombe, 2010). Whether or not geometric information is processed through a modular, pre-attentive process, it is likely that landmark use depends on attention (see Doeller & Burgess, 2008) and that it is enhanced by increases in landmark size (i.e., a red wall compared to a red patch on a wall; see Gouteux et al., 2001). [1]

Although many studies report limited or no effects of practice on children's success in the disoriented search task (e.g., Wang et al., 1999, Learmonth et al., 2002), one important study demonstrated that some forms of experience can boost children's ability to integrate the landmark into search, even in a small space. Twyman, Friedman, and Spetch (2007) pre-trained four- and five-year-old children in a room shaped like an equilateral triangle with each wall a different color (yellow, blue, and red). The object was always hidden at the center of the yellow wall. Once children achieved a criterion of three correct searches in a row, they were taken to a rectangular room with one yellow wall where the object was hidden in a corner adjacent to the yellow wall prior to disorientation. Children with the yellow-wall pre-training were more likely

[1] Learmonth, Newcombe, Sheridan and Jones (2008) showed that four trials of experience with the disorientation task in a large rectangular space enhanced children's ability to integrate the landmark on four subsequent trials when the children's movement was restricted to the size of the smaller space (by having to stay inside a taped area). However, the arena itself in which the task was performed was large, with all properties other than locomotion (e.g., the distances between hiding locations, size of the landmark wall, visual angles subtended by landmark wall) corresponding to a large arena. There are apparently no beneficial effects of practice in a large space on children's performance in a small arena (Learmonth, Nadel, & Newcombe, 2002).

to attend to the yellow wall landmark than children with no pre-training. This finding demonstrates that children, like animals, can be given experience that supports the integration of landmarks into their search behavior following disorientation, even though they would not use the landmark spontaneously. However, there are a number of caveats to strong interpretations of this study. First, many of the children were at or near five years of age, and therefore may have begun the process of acquiring relevant spatial language. Second, the target location was always at the yellow wall. This design raises the possibility that children restricted their choices to the two geometrically appropriate corners and then selected the one that was 'at the yellow wall,' without truly integrating the spatial relation between the yellow wall and the target object.

Both children and animals are substantially more successful at using surface color, surface markings, or objects as direct landmarks – indicating the location at which the object is hidden – than as indirect landmarks – indicating a location a certain distance and direction from the hidden object (Biegler & Morris, 1996; Lee, Shusterman, & Spelke, 2006; Nardini et al., 2008). The advantage of direct over indirect landmark use holds for spatial tasks other than disorientation (Acredolo, 1978; Bushnell, McKenzie, Lawrence, & Connell, 1995; Sutton, 2006). For example, when 12-month-old children had to retrieve an object hidden in an array of cushions, one of which had distinctive properties, they successfully retrieved the object when it was hidden under the distinctive cushion but not when it was hidden elsewhere (Bushnell et al., 1995). Likewise, two-year-old children given a touch-screen search task found a cartoon character when he was hidden behind a distinctive item on the screen, but not when he was hidden behind one of several identical items distinguishable only by the neighboring pictures (Sutton, 2006). The vulnerability of indirect landmark representations has also been documented in much younger children using an anticipatory looking method (Lew, Foster, & Bremner, 2006).

Finally, navigation by landmarks calls on cognitive and neural processes distinct from those used for navigation according to the geometry of the surrounding layout. Geometric relations are learned easily by many species (e.g., Tommasi & Thinus-Blanc, 2004), whereas learning of landmarks is more effortful and vulnerable to interference (Knierim, Kudrimoti, & McNaughton, 1995). In rats, learning of environmental geometry is supported by the hippocampal formation: the firing fields of cells in the hippocampus, attuned to the rat's position, change when the lengths of the walls are altered (Tommasi & Thinus-Blanc, 2004), but not when each wall of the environment undergoes dramatic changes in color, texture, and composition while retaining its distance and direction relative to the animal (Lever, Wills, Cacucci, Burgess, & O'Keefe, 2002).

Similarly, human adults encode environmental geometry more readily and automatically than environmental landmarks. When adults must remember and relocate an object while navigating through a virtual environment, they automatically encode the position of the object relative to the shape of extended surfaces that form borders of the surrounding layout (Doeller & Burgess, 2008), as do rats (O'Keefe & Burgess, 1996). Adults encode the object's position relative to a stable landmark object as well, but landmark encoding is demanding of attention and subject to interference (Doeller & Burgess, 2008), and it depends on neural structures that are distinct from those that encode environmental boundaries (Doeller, King, & Burgess, 2008; see also Sutton, Joanisse, & Newcombe, 2010). Furthermore, people with Williams Syndrome, a genetic disorder characterized by impaired spatial cognition, show reduced activity in the hippocampus, and they fail to use the geometry of the space in the classic reorientation task when no landmark is present (Lakusta, Dessalegn, & Landau, 2010). However, they are able to solve the task when a landmark is present, suggesting that the genetic deficit selectively impairs use of geometry. Collectively, these findings provide evidence that navigating by landmarks is more fragile than navigating by the layout of extended surfaces.

Language and the Development of Mature Landmark Strategies

In contrast to animals and children, human adults use indirect landmarks frequently to locate objects, whether they are oriented or disoriented. In the red wall disorientation task that Hermer and Spelke's 18-24 month-old children failed, adults robustly succeed (Hermer & Spelke, 1996). The transition to mature performance in this paradigm occurs between 5 and 7 years of age (Hermer-Vasquez et al., 2001). Four lines of evidence suggest that this developmental change depends, in some way, on language.

First, verbal interference decreases disoriented adults' accuracy at locating an object in relation to an indirect landmark; adults continue to rely on geometry in a rectangular room, but are impaired at distinguishing the correct corner from the opposite one (Hermer-Vasquez, Spelke, & Katsnelson, 1999; Ratliff & Newcombe, 2008b; note that spatial interference also impairs performance, Ratliff & Newcombe, 2008b). Interestingly, verbal interference does not impact adults' performance in a large room, where children also succeed (Hupbach, Hardt, Nadel, & Bohbot, 2007), and its effect is smaller when the task is explained to the participants in advance, allowing them to focus attention strategically (Ratliff & Newcombe, 2008b). Second, children's success on disoriented search tasks is correlated with productive use of spatial language, specifically the phrases 'left of X' and 'right of X' (Hermer-Vasquez et al., 2001; Shusterman & Spelke, 2005). Third, linguistic encoding is instrumental in supporting children's ability to represent left-right relations in visual memory tasks (Dessalegn & Landau, 2008; see also Haun et al., 2006). Finally, adults with less than full linguistic input, who show limitations in their mastery of left-right spatial language, also show impaired performance on the reorientation task despite otherwise normal trajectories of cognitive maturation and experience (Pyers et al., 2010).

Some researchers have questioned the claim that language supports spatial reorientation. In the Williams Syndrome population, neither comprehension nor production of left and right correlated with the ability to solve the task, suggesting that spatial language alone cannot enhance spatial performance in people with severely impaired spatial abilities (Lakusta et al., 2010). Additionally, there is controversy over why the correlations with linguistic ability or the effects of verbal shadowing disappear in a large room rather than a small one (Hupbach et al., 2007). Nevertheless, the findings that left-right language are strongly tied to performance on the task in a small-room setting are robust and replicated across age groups (children and adults), labs, and language groups (spoken English, Nicaraguan Sign Language), despite the fact that the boundary conditions of these effects are not completely understood.

If language fosters spatial development, how might it do so? One family of hypotheses proposes that language can serve as a medium for combining information from domain-specific reasoning systems (Carruthers, 2005; Spelke, 2003). Navigation tasks highlight the limited combinatorial capacities of untrained animals and young children, who readily represent object concepts like *red wall* and geometric relational concepts like *left of the short wall*, but not concepts that span these domains, such as *left of the red wall*. On these views, learning the relevant vocabulary and syntax underlying a phrase like "left of the red wall" allows a child to combine the geometric concept *left* with the object concept *red wall*. The consequence of this new, unitary representation is an ability to flexibly orient by anything that could stand for X in the phrase "left of X."

On its strongest version, the linguistic combination hypothesis predicts that the two parts of language important for landmark use in reorientation are spatial vocabulary and syntax, which provides a framework to link concepts from distinct cognitive domains. Accordingly, in the absence of mastery of spatial expressions involving the terms *left* and *right*, untrained children tested in a range of environments should not be expected to succeed on using a landmark during reorientation.

There are at least three other roles that language could play in landmark use following disorientation. First, language might boost the salience of the landmark and guide attention to relevant landmarks. Relatedly, language might provide an economical description of the environment and thereby improve memory for landmark-target relations. In either of these cases, simply saying "red wall" should help the child to attend to and remember the red wall landmark. Alternatively, language might lead the child to construe the landmark in a new way, as a pointer to another location rather than solely as an object in its own right. The studies presented here investigate each of these possible roles for language in the development of spatial cognition.

The Present Studies

Our research focuses on four-year-old children, who have repeatedly been shown to fail to use landmarks as indirect cues in disoriented search tasks (Hermer-Vasquez et al., 2001; Learmonth et al., 2002; Lee et al., 2006) but are on the cusp of the age where children succeed (Hermer-Vasquez et al., 2001; Shusterman & Spelke, 2005) and are well advanced in acquiring their native language. We reasoned that such children will understand a variety of verbal descriptions and may be prepared to learn to use landmarks during disorientation, but they will not use indirect landmarks spontaneously. The linguistic context in which the search task took place was varied across these studies to see whether particular properties of language could tip the scales toward success on this task.

Linguistic context was manipulated using verbal expressions that varied in their informativeness and their linguistic structure. Experiments 1 and 2 presented a spatial expression that mentioned wall color but lacked the critical words *left* and *right*: “I’m hiding it at the red wall.” Experiment 3 presented non-spatial language that mentioned the color of the landmark wall: “Look at the pretty red wall! I’m hiding it over here.” Experiment 4 presented non-spatial but task-relevant language that mentioned wall color: “The red wall can help you get the sticker.”

The pattern of findings across these conditions should serve to test each of the four potential effects of language on navigation. First, if language exerts its effect by helping children attend to and remember the relevant wall color, then all of the cues should be beneficial. This finding would suggest that the activation of the phrase “red wall” is a sufficient condition for success. Second, if language prompts the child to construe the landmark as a pointer to the hiding location, then any task-relevant language (Experiments 1, 2, and 4) should be more helpful than mere reference to the landmark (Experiment 3). This pattern of results would suggest that the benefit is constrained by whether the linguistic structure of the cue causes the landmark wall to be construed as relevant for the spatial behavior. Third, if specifically *spatial* language, but not other language, enables the child to incorporate the landmark into spatial behavior, then spatial expressions (Experiments 1 and 2) should help most of all. Finally, if left-right language is the only kind of language that can support success on this task, then none of these cues should enhance children's performance, since none present spatial expressions using the words *left* or *right*.

General Methods

Participants

Participants were 88 4-year-old children (mean 4;3; range 3;11 to 4;8) who came into our laboratory with their parents. Parents provided informed consent in accordance with university IRB standards. Participating families received a small toy and a $5.00 travel reimbursement.

Apparatus

The apparatus (a rectangular room 1.2 m x 1.8 m) followed the parameters described by Hermer and Spelke (1994, 1996). The apparatus was enclosed in a sound-proof environment with symmetrically placed lights of equal brightness that provided even lighting in all four target corners. One short wall was entirely covered in bright red felt, and the other three walls were neutrally colored. A door was formed by a panel in one of the long walls away from the red landmark wall. Once closed, the door was not visually distinguishable from the other neutral panels in the room. One hiding place was located in each corner.

Two different apparatuses were used, one in Experiments 1 and 2, the other in Experiments 3 and 4. Extensive testing revealed no differences in children's behavior; in both apparatuses, 4-year-old children successfully used geometric cues at the same rate (consistently about 80%) and failed to use landmarks in the absence of verbal cues.

The apparatus in Experiments 1 and 2 was a rectangular room with dimensions 1.2 m x 1.8 m x 1.8 m. The interior was lined with white felt on three of the walls and red felt on one short wall. Panels covered with dark blue felt were hung in each corner to create hiding places. The exterior of the entire room was covered in light-proof fabric to create a ceiling for the room and to block out ambient light.

The apparatus for Experiments 3 and 4 was made from pre-fabricated conference booth panels arranged into a 1.2 m x 1.8 m rectangle (10 0.6 m x 0.9 m panels, Panel Plus System, Budget Trade Show Displays). The apparatus stood 3' (.9 m) high, just above eye height of most of our participants, and was open at the top. It was situated exactly in the center of a soundproof 3 m x 3 m square white room with symmetrical lighting. The interior was gray except for the one red wall. Four blue containers, 10 cm in diameter and 2 cm tall, were positioned flush within each corner of the room to serve as hiding places for the stickers.

Procedure

The procedure followed Hermer and Spelke (1994, 1996). The child entered the room with the experimenter, who then sealed the door closed. The experimenter drew the child's attention to the sticker and hid the sticker in one of the four corners while the child watched. The child then moved to the center of the room, put on a blindfold, and turned at a medium pace approximately 3 to 4 times to become disoriented. Once disorientation was ensured (see Manipulation Check), the child was turned to face a predetermined direction, removed the blindfold, and searched for the sticker. To avoid unintentionally biasing the child's search with gazes toward any of the hiding corners, the experimenter stood behind the child to remove the blindfold and fixated on the ceiling or the child's eyes during search.

Instructions

Before entering the testing room, the experimenter explained to the children that they would play a "sticker treasure hunt" game. Children were told that they would watch the experimenter hide a sticker in a special hiding place inside the sticker hunt room, put on a blindfold and turn in circles, stop when the experimenter said so, and look for the sticker. They were instructed that they had to find the sticker on the first try, and that there were 8 stickers so they would have 8 chances to play.

Manipulation check

In the present experiments, children could search successfully either by using the landmark after disorientation or by maintaining their sense of orientation during the turning procedure. To ensure that success depended on use of the landmark, disorientation was assessed for each child on every trial. During the turning procedure and prior to the search test, the experimenter asked the blindfolded child to point to the door. Children who pointed to an incorrect direction (more than about 15 degrees on either side of the correct direction) were presumed to be disoriented and were turned once or twice more to face the planned direction, whereupon the blindfold was removed. Children who pointed to the door were presumed to be oriented, and were turned several more times. No feedback was given. This procedure was repeated until the child either pointed away from the door or lost patience with the procedure. Trials for which disorientation was not ensured were discarded and replaced with an additional trial at the end of that block. This happened approximately once for every three participants (about 1/24 trials).

Counterbalancing

Participants received two blocks of four trials each. Within a block, all four trials used a single hiding corner to minimize perseverative errors and proactive interference[2]. The hiding corner in the second block differed on both geometry (i.e., which diagonal) and proximity to landmark (i.e., near or far). Children faced a different wall on each trial within a block. A Latin-

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[2] By proactive interference, we mean the influence of the hiding location during a previous trial on children's memory during subsequent trials. For control children, accurate use of geometry fell after the hiding location changed between Blocks 1 and 2. This was most likely because children's representation of the old hiding location interfered with their ability to encode and remember the new hiding location, which was always on the opposite diagonal.

squares design yielded four possible facing orders. Each hiding corner was combined with two of the possible orders of facing directions, resulting in eight corner-order combinations.

--- FIGURE 1 ABOUT HERE ---

Verbal cue conditions

Children in the control condition (reported in Experiment 1) received two blocks of No Cue trials. All other children received one block of trials with No Cue and one block of Cue trials. In Experiments 1, 3, and 4, the cue was given in Block 2. In Experiment 2, the cue was given in Block 1.

Coding

We coded the first search of each trial, defined as the first place where the child displaced the cover to retrieve the hidden sticker. Each search was marked as correct (C), rotational error (R), near error (N), or far error (F), as shown in Figure 1. Points, looks, and searches other than the first one were not analyzed.

Measures

The primary measure of children's performance was the difference between search rates at the correct corner and at its geometric equivalent with the incorrect relationship to the landmark, rather than overall correct performance. Although the latter measure is used in many studies, it cannot differentiate between effects that are attributable to increased reliance on geometry, increased reliance on the landmark wall, improvements in attention or memory for the hidden object's location, enhancements in motivation, or a combination of these factors. The difference score restricted the analysis to the two geometrically correct options, allowing us to see whether performance increases were specifically due to children's use of the landmark. A difference score (C-R) therefore was calculated for each subject. Scores above zero indicate more searches at C than R, and a higher difference score indicates more accurate search with respect to the landmark. For descriptive purposes and to facilitate comparison with other studies, however, we also include information about three other dependent variables: (1) overall geometric search (i.e., search C+R), (2) overall correct search (i.e., search at C), and (3) the number of children who improved from Block 1 to Block 2 in each condition.

Preliminary analyses

A preliminary omnibus ANOVA, using all of the children in the study, tested for effects of Block (Repeated Measure: First, Second), Wall Order (Red First, White First), Sex (Male, Female), and Group (Control, Exp. 1, Exp. 2, Exp. 3, Exp. 4), with Age in Months as a covariate on overall correct search and on difference score. Both dependent measures showed the same pattern. For difference score, there was a main effect of Group, $F(4,67) = 4.72$, $p = .002$, a significant interaction of Block * Group, $F(4,67) = 5.143$, $p = .001$, a significant interaction of Block * Wall Order, $F(1,67) = 6.907$, $p = .011$, and no other significant effects or interactions. For overall correct, there was a main effect of Group, $F(4,67) = 4.23$, $p = .004$, a significant interaction of Block * Group, $F(4,67) = 4.70$, $p = .002$, a significant interaction of Block * Wall Order, $F(1,67) = 7.17$, $p = .009$, and no other significant effects or interactions.

The Block * Group interaction is due to differential benefits of the different verbal cues, which are explained in detail in each experiment. The Block * Wall Order interaction comes from the fact that, collapsing across experiments, children were more accurate in Block 2 with targets near the red wall (diff score = .63) than with targets that were far from it (diff score = .39); this difference did not appear in Block 1. Thus, a benefit for locations adjacent to the landmark can be observed in this age group, but only with some experience. Specifically, experience with a contrast between trial blocks (i.e., going from a neutral-wall target to a red-wall target) may help children to use the red wall as a proximal marker of location (see Table 1, presented with Experiment 4, for an experiment-by-experiment breakdown of performance as a function of wall color).

Wall Order was tested in preliminary analyses for each experiment. Data were collapsed across sex and age prior to analysis since these did not yield significant effects in the ANOVA. However, because sex differences are sometimes reported in studies of the development of spatial cognition (e.g., Geary, Saults, Liu, & Hoard, 2000), we tested for such differences in post-hoc analyses group by group (controls and the four experimental groups) using t-tests. We only found significant effects in the control group, described in a footnote to Experiment 1.

To test the central hypotheses, planned t-tests were used to analyze effects of the verbal cues in each experiment relative to chance, relative to baseline trials, and relative to the control group. The performance of each experimental group was compared to the control group, which is described in detail in Experiment 1.

Experiment 1

Experiment 1 Overview and Methods

Experiment 1 tested the effect of a richly informative expression that focused on a spatial aspect of the hiding location without using the words "left" or "right." Sixteen 4-year-old children (7 girls, 9 boys; mean age 4;4; range 4;1 to 4;6) participated in the experimental condition. A separate group of 16 children (9 girls, 7 boys, mean age 4;5; range 4;2 to 4;8) participated in the control condition.[3] All children received No Cue trials in Block 1. In Block 2, children in the experimental condition received Cue trials, while those in the control condition received more No Cue trials. On each No Cue trial, the Experimenter said something neutral to draw the child's attention to the hiding event (e.g., "I'm hiding the sticker over here"). On each Cue trial, the experimenter said "I'm hiding it at the red wall" or "I'm hiding it at the white wall" as she hid the sticker and the child watched.

Analyses served to test the contrasting outcomes outlined above. If the cue had no benefit, since it did not employ left-right language, then children in both conditions should have searched equally at the two geometrically specified locations (C and R). If the cue increased children's attention to the landmark wall at the expense of their attention to room geometry, then children in the experimental condition should have searched equally at the two corners close to the landmark (C and N), while control participants should have searched equally at the two geometrically appropriate corners C and R. Finally, if the cue increased children's ability to use the landmark as an indirect reference to the hiding location, then children in the experimental condition should have searched more at the correct than at the opposite location (C-R).

Experiment 1 Results

No effects of order (first hiding location at red wall vs. white wall) on the dependent variables were significant in either group, so subsequent analyses collapsed across this variable.

We first looked for the signature pattern of reliance on geometric cues. Children reliably confined their search to the geometrically appropriate corners (C and R), searching at these two

[3] In post-hoc tests for sex differences, the only statistically significant effect we found was in the control group in Block 2. Boys outperformed girls on Block 2 correct search, 61% vs. 33%, $t(14) = 2.38$, $p = .03$; boys' difference scores and geometry scores were both higher than girls'. We did not observe any statistically significant sex differences in Block 1 search. This suggests that boys may benefit from experience with the room and the task more so than do girls, replicating Hoyos, Nuzzi, and Shusterman (2011).

corners out of the possible four at rates above 50% chance. Children in the control condition searched geometrically 78% of the time in Block 1, $t(15) = 5.58$, $p < .001$, and 66% in Block 2, $t(15) = 2.30$, $p < .05$. Children in the experimental condition searched geometrically 89% of the time in Block 1, $t(15) = 8.60$, $p < .001$, and 84% in Block 2, $t(15) = 6.21$, $p < .001$. Children in the experimental condition searched geometrically more than controls in Block 2, $t(30) = 2.14$, $p < .05$, but not in Block 1, $t(30) = 1.59$, $p = .12$.

To test whether the verbal cue increased children's reliance on the landmark, we used the C-R difference score to restrict the analysis to trials where children search the geometrically correct corners. Focusing on these trials minimizes the contaminating effects of proactive interference, which were observed in the control group as an increase in non-geometric errors from 11% in Block 1 to 17% in Block 2. The mean difference scores were .13 in Block 1 and .25 in Block 2 for the control group, and .03 and .69 for the Experimental group (Figure 2). A 2x2 (Block x Group) Repeated Measures ANOVA revealed a main effect of Block, $F(1,30) = 10.62$, $p < .005$, and a Block x Group interaction, $F(1,30) = 4.94$, $p < .05$, indicating that the verbal spatial expression given to children in the Experimental condition helped them to use the red wall to distinguish between the geometrically equivalent corners. The difference scores of the experimental group significantly increased in accuracy between Blocks 1 and 2, $t(15) = 3.96$, $p = .001$, whereas those of the control group did not, $t(15) = 0.72$, $p = .48$. In the control group, 8/16 children (50%) showed an increase in difference scores between Block 1 and Block 2, whereas in the experimental group, 12/16 (75%) children improved.

Analysis of overall correct search paralleled the difference score results. Children in the control group searched in the correct corner 45% in Block 1 and 45% in Block 2 (Figure 2). Children in the test group searched correctly 46% of the time in Block 1, when they did not receive a verbal cue, but 77% of the time in Block 2, when they received a cue on each trial. A 2x2 Block (1, 2) x Group (Control, Experimental) repeated measures ANOVA, with correct search as the dependent measure, revealed a significant main effect of Group, $F(1,30) = 4.62$, $p < .05$, a significant main effect of Block, $F(1,30) = 4.55$, $p < .05$, and a significant Block x Group interaction, $F(1,30) = 4.55$, $p < .05$. The increase between Blocks 1 and 2 was significant for the experimental group, $t(15) = 3.96$, $p = .001$, but not for the control group, $t(15) = 0$, $p = 1$. In the control condition, 5/16 children (31%) improved from Block 1 to Block 2, whereas in the experimental group, 11/16 children (69%) improved.

--- FIGURE 2 ABOUT HERE ---

Experiment 1 Discussion

The verbal expression used in Experiment 1 had a clear benefit: children's performance after hearing this expression was better than their own performance without the expression and better than the performance of a control group. Children showed no decrease in their use of geometry when given a verbal cue about a landmark: the spatial expression did not increase search at the geometrically incorrect corner at the labeled wall (corner N) for children in the experimental condition, relative to their own baseline no-cue trials or controls. This finding suggests that children's response patterns did not simply switch from geometry-based responding to landmark-based responding. Instead, the spatial expression led children to integrate the landmark into their representation of the target location.

Curiously, children benefitted from the verbal expression as much when the object was hidden on the side of the room opposite to the red wall, accompanied by the expression "I'm hiding it at the white wall," as when the object was hidden on the side of the room containing the red wall, accompanied by the expressions "I'm hiding it at the red wall." Children's equal benefit from reference to the white and red walls is striking, because the room contained three white walls but only one red one. Children may have intuited that the experimenter was referring to the short white wall across from the distinctive red wall, and have remembered it by virtue of its unique length (the short white wall) or its relation to the landmark (across from the red wall). Alternatively, children may have used room geometry to narrow their search to two locations (the corners to the left or right of a short wall) and then used the color term to distinguish between these locations. In either case, the equal benefit of the verbal expression when given at the red or white walls suggests that the expression sparked a richer conceptual understanding than a simple association between the salient landmark (the red wall) and the target location.

Experiment 1 left us with two immediate questions. First, was the benefit of the cue completely local and independent for each trial, or did children actually learn a new way of thinking about the task as a consequence of hearing the spatial expression? Second, did the contrast between the Block 1 and Block 2 hiding locations facilitate children's ability to use the expression? The Block 2 hiding location always differed both in geometry (which diagonal of the rectangle held the hiding corner) and in proximity to the landmark (if the sticker was hidden at the white wall in Block 1, it was hidden at the red wall in Block 2). The control group showed a trend toward decreased reliance on geometry between Block 1 and Block 2, but they improved in discriminating the correct corner relative to its rotational equivalent as shown by the increase in C-R difference scores. Apparently, the mere act of changing hiding locations between blocks motivated some attention to the relation between the target location and the landmark. This finding raised the possibility that the cue benefit in the test group depended in part on a more primitive contrast benefit, and that the cue benefit would diminish or disappear if given in Block 1. To address these two issues, we tested a new group of children with the same verbal expression delivered in Block 1 instead of Block 2.

Experiment 2

Experiment 2 Overview and Methods.

Sixteen 4-year-old children (10 girls and 6 boys; mean age 4;4; range 3;11 to 4;8) participated in Experiment 2. On Cue trials, children heard the same cue that was used in Experiment 1: "I'm hiding it at the red wall" or "I'm hiding it at the white wall." The Cue trials were given in Block 1 and the No Cue trials in Block 2.

If the effect of language was local to every trial, then the cue benefit should stop once the cue is no longer given. On the other hand, if language affects the child's attention to the landmark or conceptualization of the room and the task, then a strong cue benefit should be observed even in Block 1, and this benefit might carry over into Block 2. Finally, if language only helped to increase attention to the contrast between the Block 1 and Block 2 hiding locations, then a cue delivered in Block 1 should have a smaller effect than in Experiment 1.

Experiment 2 Results

We first analyzed children's responses based on geometry (corners C and R). As in Experiment 1, children searched predominantly at the two geometrically appropriate corners (Block 1: 78%, $t(15) = 7.68$, $p < .001$; Block 2: 66%, $t(15) = 4.39$, $p = .001$). Children's correct search with respect to the geometry of the room did not differ from controls in either block. However, children hearing the verbal expression searched more geometrically in Block 1, when the expression was present, than in Block 2, when it was not, 89% vs. 78%, $t(15) = 2.41$, $p < .05$.

Children who received the verbal expression in Block 1 used the landmark more accurately than controls (from Experiment 1) both in Block 1 (diff score = .64) and Block 2 (diff score =.63). A 2x2 (Block x Group) repeated measures ANOVA yielded only a main effect of Group, $F(1,30) = 14.30$, $p = .001$. Overall correct scores were 77% in Block 1 and 70% in Block 2 (Figure 3). A 2x2 Block (1,2) x Group (Control, Test) Repeated Measures ANOVA, with correct search as the dependent variable yielded only a main effect of Group, $F(1,30) = 13.89$, $p = .001$.

The effect of the verbal expression was observed in both blocks of this experiment. Children's difference scores (C-R) for Block 1 were significantly higher than controls, 0.64 vs. 0.13, $t(30) = 3.10$, $p < .005$. Children hearing the informative spatial expression searched more accurately than control subjects, 77% vs. 45% correct, $t(30) = 3.26$, $p < .005$. In Block 2, when the informative spatial expression was no longer given, children in the cueing condition still used the landmark more accurately than controls, 0.63 vs. 0.25, $t(30) = 2.37$, $p < .05$, and they had higher overall search accuracy for Block 2 than controls, 70% vs. 45% correct, $t(30) = 2.42$, $p < .05$. The carryover benefit on Block 2 trials was not weaker than the benefit observed on the cued trials in Block 1: children's difference scores did not differ between cued and uncued blocks, $t(15) = .11$, $p = .91$, nor did their accuracy, $t(15) = .75$, $p = .47$. Accordingly, few children showed improvement from Block 1 to Block 2: 5/16 (31%) for difference score, and 4/16 (25%) for overall correct. Finally, both the cue benefit in Block 1 and the carryover benefit in Block 2 were as strong as the cue benefit observed in Experiment 1. In Block 1, children in Experiment 2, who received a verbal cue, performed more accurately than children in Experiment 1, who did not, $t(30) = 3.52$, $p = .001$ for difference score, $t(30) = 2.98$, $p < .01$ for search accuracy. In

Block 2, children in the cueing conditions of Experiments 1 and 2 performed equally well, t-values <1 for both measures.

--- FIGURE 3 ABOUT HERE ---

Experiment 2 Discussion

Experiment 2 replicated the findings of Experiment 1, demonstrating a strong effect of a verbal spatial expression on children's ability to use a landmark following disorientation. The cue benefit was as strong when delivered in Block 1 as Block 2, indicating that the contrast benefit observed in the control group did not interact with the cue. In addition, Experiment 2 revealed a new, delayed effect of language on children's search performance: children who heard the expression in Block 1 continued to search accurately in Block 2, despite the absence of any relevant verbal information. Children's accuracy in Block 2 of Experiment 2 reliably exceeded the accuracy of children in the control condition of Experiment 1, despite the fact that the testing procedure was identical in these two conditions. These results provide evidence that the verbal information presented in Block 1 had enduring effects on children's representations of the environment.

Experiments 1 and 2 did not use the sophisticated spatial language that has been previously correlated with success on this task, phrases like "left of the red wall." Nevertheless, the expression had spatial content from the preposition "at." The prepositional phrase "at X" may have sufficed to improve children's ability to incorporate X into their search, even though correct search required that children orient correctly to the left or right of the landmark wall.

What aspect of this verbal expression helped children to use wall color to guide their search? Was the spatial content of the expression critical, or was the mere mention of the landmark wall sufficient for success? Experiment 3 was undertaken to distinguish between these possibilities.

Experiment 3

Experiment 3 Overview and Methods

Experiment 3 tested whether the verbal description enhanced children's search in Experiments 1 and 2 by enhancing their attention to or memory for the landmark object. To test these possibilities, the experiment used the method of Experiment 1 with a new environment (a gray room with a single red wall), and a new verbal description, designed to call children's attention to the landmark without providing specifically spatial information about it. Sixteen 4-year-old children (9 girls and 7 boys; mean age 4;3; range 4;0 to 4;6) who had not participated in the previous experiments were tested in this experiment. As in Experiment 1, children received No Cue trials in Block 1 and Cue trials in Block 2. On each Cue trial, the Experimenter said "Look at the pretty red wall! I'm hiding the sticker over here," or "Look at the pretty gray wall! I'm hiding the sticker over here."

If mere mention of the landmark wall was sufficient to assist children in using that wall following disorientation, then this expression should help. If, on the other hand, children needed more information in order to understand *how* to use the landmark wall, then this expression should not help given that it conveys no information suggesting that the child should encode the hidden object's location relative to the position of a colored wall.

Experiment 3 Results

Children searched predominantly at the geometrically appropriate corners C and R [77% in Block 1 and 81% in Block 2, $t(15) > 5.59$, $p < .001$ compared to 50% chance for both blocks]. Children in this experiment showed marginally greater geometric search in Block 2 than controls from Experiment 1, 81% vs. 66%, $t(30) = 1.95$, $p = .06$.

A difference score (C–R) was calculated to restrict analysis to the geometrically appropriate corners. Mean difference scores were .08 in Block 1 and .28 in Block 2. A 2x2 (Block x Group) repeated measures ANOVA with difference scores as the dependent measure revealed no main effects or interactions. Children searched correctly 42% and 55% in Blocks 1 and 2, respectively (Figure 4). A 2x2 Block (1, 2) x Group (Control, Test) repeated measures ANOVA, with correct search as the dependent measure, revealed no significant main effects or interactions. Thus, children hearing the Mentioning expression did not search more accurately than controls. Ten out of sixteen (63%) increased in their difference score, and seven out of sixteen children (44%) in Experiment 3 improved between Blocks 1 and 2 on overall accuracy.

--- FIGURE 4 ABOUT HERE ---

Children's performance in Experiment 3 (with the Mentioning expression) was compared to performance in the experimental condition of Experiment 1 (with the Spatial expression). A 2x2 Block (1, 2) x Experiment (1, 3) ANOVA with difference score as the dependent measure yielded a main effect of Block, $F(1,30) = 18.90$, $p < .001$, and a significant Block x Group interaction, $F(1,30) = 5.31$, $p < .05$. An ANOVA with the same factors using search accuracy as the dependent measure yielded a main effect of Block, $F(1,30) = 11.98$, $p = .002$, and no other effects. Children receiving the Spatial expression outperformed children receiving the

Mentioning expression on Block 2 difference score, $t(30) = 2.61$, $p < .02$, and Block 2 correct search, $t(30) = 2.16$, $p < .05$, but not on Block 1 measures with no expressions, t-values <1. Thus, children hearing the Spatial expression were specifically better at integrating the landmark into their search, relative to children hearing the Mentioning expression.

In contrast to the previous experiments, an effect was found in Experiment 3 for the order of hiding locations (red wall in Block 1 and gray wall in Block 2, or vice versa). Specifically, children who received the cue during Block 2 at the red wall ("look at the pretty red wall") were significantly more accurate than children who received the cue at the gray wall, .50 vs. .06, $t(15) = 2.20$, $p < .05$. This order effect was also found for search accuracy: Children with a red-wall target location in Block 2 searched correctly 69% of the time, while children with gray-wall targets searched correctly only 41% of the time, $F(1,15) = 6.23$, $p < .05$. This suggests that the Mentioning expression might have helped draw children's attention to the red wall, but in a rather limited way.

Given this result, we systematically analyzed the results from Experiments 1 and 3 controlling for order effects. A one-way ANOVA on Block 2 difference scores, with Group as the independent factor (3 levels: No cue, Spatial expression, Mentioning expression) and Order as a covariate (2 levels: Red first, White first), yielded a significant main effect of Order, $F(1,44) = 4.10$, $p < .05$, and a significant main effect of Group, $F(1,44) = 5.21$, $p < .01$. Children whose Block 2 target was at the red wall (diff score = .53) were more accurate than children whose Block 2 target was at the neutral wall (diff score = .28). However, the difference between wall colors was significant only for the Experiment 3 (Mentioning expression) group, $t(14) = 2.20$, $p = .05$, and not for controls, $t(14) = 0$, $p = 1$.

Finally, to understand the effect of experimental condition on children's ability to integrate the landmark, children hearing the Mentioning expression were compared to controls and to children hearing the Spatial expression in separate one-way ANOVAs controlling for Order, with Block 2 difference scores as the dependent measure. We first compared children hearing the Mentioning expression to controls, and found no difference between conditions. However, there was an overall effect of Order, $F(1,29) = 6.71$, $p < .02$, with an overall benefit for locations at the red wall. Children receiving the Mentioning expression at the red wall did not perform significantly better than red-wall controls, .50 vs. .41, $t(15) = .50$, $p = .63$, indicating that drawing children's attention to the red wall did not significantly enhance their use of this landmark during search. We then compared children hearing the Mentioning expression to children with the Spatial expression from Experiment 1, revealing a main effect of Group, $F(1,29) = 7.07$, $p < .02$, but no effect of Order, $F(1,29) = 2.05$, $p = .16$. Thus, in contrast to the Spatial cue, the Mentioning expression had little effect on children's landmark use.

Experiment 3 Discussion

Overall, the Mentioning expression conferred a small benefit in reducing proactive interference between Blocks 1 and 2, as indicated by marginally more reliance on geometry in Block 2 relative to controls. However, the Mentioning expression did not help children to incorporate the landmark wall into search for the hidden sticker, relative to controls, as indicated by the similar patterns of difference scores for controls and cued children. We conclude that the mere mention of the landmark wall does not promote orientation by that landmark. Therefore, effects of language on spatial behavior are a consequence of how a landmark is conceptualized, not whether the landmark is named.

While the results of Experiments 1-3 indicate that not all verbal expressions that refer to a landmark object enhance children's landmark-guided search, they do not reveal what properties of a verbal expression make it useful. There were several differences between the Spatial and the Mentioning expressions. In Experiment 3, information about the landmark and the target was spread across two sentences; it is possible that this framing did not invite the child to link these pieces of information together. Another difference is that the Mentioning expression focused on an irrelevant, non-spatial property of the landmark (i.e., the attractiveness of the red or grey wall), whereas the Spatial expression used the task-relevant, spatial prepositional phrase "at the red wall." To find out whether *only* spatial language would confer a benefit, we ran a new condition using a non-spatial single-sentence expression. Experiment 4 tested the possibility that a verbal expression focusing on the *function* of the landmark would help children to search in relation to that landmark, even if the expression contained no spatial language.

Experiment 4

Experiment 4 Overview and Methods

Experiment 4 tested whether verbal descriptions enhance children's navigation by landmarks by providing children with information about landmark's spatial position, as in Experiments 1 and 2, or with information about the relevance of the landmark to the navigation task. 24 4-year-old children (10 girls and 14 boys; mean age 4;2; range 3;11 to 4;6) who had not participated in the previous experiments were tested. On each Cue trial in Block 2, the experimenter said "The red wall can help you get the sticker" or "The gray wall can help you get the sticker."

We created three conditions: (1) red-red trials, where the cue made reference to the distinctive red wall and the hiding corner was to the left or right of a red wall, (2) gray-gray trials, where the cue made reference to a non-distinctive gray wall and the hiding corner was at the intersection of two gray walls, and (3) red-gray trials, where the cue made reference to the distinctive red wall but the hiding place was at the short gray wall. Consequently, 8 children saw the sticker hidden at the red wall in the second block (condition 1), and 16 children saw the sticker hidden at the gray wall in the second block (conditions 2 and 3). To correct for this asymmetry, order (Red in Block 1 vs. Gray in Block 1) was used as a covariate in analyses that did not directly test for order effects.

The purpose of these conditions was twofold. The first purpose was to distinguish between the possibility that specifically spatial language is required for an effect of language on spatial behavior and the contrasting possibility that any functionally relevant language about the landmark would promote such an effect. If spatial language is needed, then the expression used in Experiment 4 should not work under any circumstances; if functionally relevant language is sufficient, then the expression should enhance children’s performance relative to controls.

The second purpose was to test whether the verbal expression promoted landmark use in a general manner, or whether it merely encouraged a direct association with a marked location. In the previous conditions, the verbal expression in any given trial mentioned the color of the target wall at the hidden object’s location. Thus, successful use of the cue could be attributed to a direct link between the verbal cue and the target color. To demonstrate non-associative landmark use, however, it is necessary to show that an expression mentioning a given landmark supports successful search at a location away from that landmark. The third condition in this study, in which the experimenter said "the red wall can help you get the sticker" when the target object was hidden at the intersection of two gray walls, tested indirect use of the red wall landmark.

Experiment 4 Results

Children searched predominantly at the geometrically appropriate corners C and R [80% in Block 1 and 85% in Block 2, $t(15) > 5.19$, $p < .001$ compared to chance for both blocks]. As before, performance was compared to the control subjects from Experiment 1. Children in the cued condition searched more geometrically than control subjects in Block 2, 85% vs. 66%, $t(30) = 2.69$, $p = .02$, but not in Block 1, $t(30) = .25$, $p = .80$.

Children's mean difference scores were -.07 in Block 1, when they did not receive a cue, and .58 in Block 2, when they received a cue on each trial. A 2x2 Block (1, 2) x Group (Control, Test) Repeated Measures ANOVA, with difference score as the dependent measure and Order as a covariate, yielded a significant Block x Group interaction, $F(1,37) = 11.80$, $p = .001$, and a significant Block x Order interaction, $F(1,37) = 5.33$, $p = .027$. The increase in difference score between Blocks 1 and 2 was significant for the test group, $t(23) = 7.09$, $p < .001$, but not for the control group. Using difference scores, 20/24 children in the test group (83%) showed improvement from Block 1 to Block 2. Children in the test group had higher difference scores than control subjects in Block 2, $t(38) = 2.22$, $p < .05$, but not in Block 1, $t(38) = 1.48$, $p = .15$. Thus, as a group, children receiving a cue performed more accurately in Block 2 than their own Block 1 performance and better than control subjects who received no cue.

Looking at percent correct, children searched correctly 36% of the time in Block 1, when they did not receive a verbal cue, and 72% of the time in Block 2, when they received a cue on each trial (Figure 5). A 2x2 Block (1, 2) x Group (Control, Test) repeated measures ANOVA, with correct search as the dependent measure and order as a covariate, revealed a significant

Block x Group interaction, $F(1,30) = 11.79$, $p = .001$, and no other effects or interactions. There was an improvement from Block 1 to Block 2 in the test group, $t(23) = 5.56$, $p < .001$, and 19/24 children showed improvement (79%). Children in the cued condition searched more accurately than controls in Block 2, $t(38) = 2.79$, $p < .01$, but not in Block 1, $t(38) = 1.121$, $p = .27$.

A focused analysis with difference scores as the dependent variable examined the effects of the three different conditions pairing wall color mention with a particular target location. A 2x3 Block (1,2) x Pairing (red-red, gray-gray, red-gray) ANOVA yielded a main effect of Block, $F(1,21) = 30.89$, $p < .001$. A parallel analysis, with correct search as the dependent variable, also revealed a significant main effect of Block, $F(1,21) = 50.61$, $p < .001$. There was no main effect of Pairing nor a Pairing x Block interaction in either analysis, suggesting that the verbal cue enhanced Block 2 performance in all three pairing conditions.

--- FIGURE 5 ABOUT HERE ---

We separately compared each pairing condition to its relevant control: children in the red-red condition were compared to control children who had a red-wall target in Block 2, and children in the red-gray and gray-gray conditions were each compared to control children who had a neutral target in Block 2. The analysis of difference scores did not quite reach significance, likely because there were only 8 children per pairing condition. In the analysis of correct performance, children in the red-red condition outperformed controls in Block 2, 81% vs. 53% correct, $t(14) = 1.78$, $p < .05$, one-tailed. Children in the all-gray condition also outperformed controls in Block 2, 66% vs. 38%, $t(14) = 2.11$, $p < .05$, one-tailed. Most importantly, children in the mixed condition, with a cue mentioning the red wall and a hiding place at the gray wall, exhibited the strongest effect of the cue relative to controls, 69% vs. 38% correct, $t(14) = 2.24$, $p < .03$, one-tailed.

Lastly, performance in Experiment 4 was compared separately to the other experiments with cues in Block 2 using a series of 2 (Block) x 2 (Group) Repeated Measures ANOVAs with difference scores as the dependent measure. Figure 6 shows the Block 1 and 2 differences scores in all four experiments. Table 1 shows the same data broken down by target location (red wall or neutral wall. The Task-relevant expression used in Experiment 4 was as effective as the Spatial expression used in Experiment 1, with no main effect of Group nor Block x Group interaction. By contrast, the Task-relevant expression was significantly more effective than the Mentioning expression used in Experiment 3, with a significant Block x Group interaction, $F(1,38) = 9.98$, $p < .01$. When search accuracy was used as the dependent measure, a Block x Group interaction was also found, $F(1,38) = 5.69$, $p < .05$, and no other effects.

--- FIGURE 6 and TABLE 1 ABOUT HERE ---

Experiment 4 Discussion

Experiment 4 demonstrated a benefit of a non-spatial but task-relevant verbal expression addressing the functional nature of the landmark. The robust success that children experienced with this expression rules out the hypothesis that only spatial language can affect spatial behavior. Instead, children show enhanced landmark-guided search when the function of the landmark is highlighted. Interestingly, the precise function of the landmark – *how* the colored wall can help – was never made explicit for the child in this paradigm. Nevertheless, the statement that the landmark *can* help is sufficient to prompt children to engage their spatial reasoning. These findings accord with the finding, from Experiments 1 and 2, that a spatial expression was beneficial even though it conveyed no information about the specific hiding location (i.e., *at the red wall*, rather than *left of the red wall*). Together, these findings suggest that verbal expressions enhance children's search by making explicit that the colored wall can serve as a landmark (i.e., *it points to the location at which I have hidden the object*) even when it fails to specify the object's position uniquely.

Additionally, Experiment 4 tested whether the observed benefits of verbal expressions were more consistent with direct or indirect use of a landmark. All of the previous experiments only tested direct use of a landmark because the landmark identified in the verbal cue was adjacent to the target location. By contrast, Experiment 4 tested the case where the landmark in the verbal expression (i.e., the red wall) could be used as a reference to a different location (i.e., at a corner adjacent to the neutral wall and opposite from the red wall). Children in this condition dramatically benefited from the cue, providing further evidence against the idea that language promoted a simple direct association between the locations of the landmark and the target.

General Discussion

The present studies demonstrate that a brief and simple verbal expression promotes four-year-old children's use of a landmark to search for a hidden object after disorientation. This finding marks the first intervention in the child reorientation literature, using the classic set-up – a small, rectangular arena, in which children typically use geometry but not landmarks – that rapidly and dramatically switches children's performance from failure to success with a simple cue and without any training trials. Although language is not the exclusive means by which children come to use landmarks, these data provide an existence proof that language is a powerful tool for shifting children's spatial behavior. In concert with previous findings, they illuminate mechanisms by which language could influence the development of mature landmark-based spatial behavior.

Children succeeded at incorporating landmark information into their search for a hidden object if they heard a verbal expression during the hiding event, but not all expressions were equally effective. A spatial expression, "I'm hiding it at the red (or white) wall" dramatically enhanced children's performance, as did a task-relevant expression, "The red (or gray) wall can help you get the sticker." In contrast, an expression that referred to the potential landmark object without encouraging a spatial or functional interpretation, "Look at the pretty red (or gray) wall!" did not enhance children's accuracy above the levels demonstrated by control participants who received no informative expression at all ("I'm hiding the sticker over here"). This finding accords with past evidence, from studies of reorientation in the absence of any linguistic information, that children's failure to use a landmark in a reorientation task is not due to a failure to notice, remember, or verbally encode it (Hermer & Spelke, 1996; Wang, et al., 1999). Rather, the typical poor use of landmarks shown by young children is likely due to a failure to construe the red wall as a landmark that can specify the target object's location. Thus, these studies suggest a mechanism through which language might enhance children's spatial representation: providing linguistic expressions can help children to construe the landmark as a reference object for a given spatial task.

Four findings from the present studies suggest that the linguistic expressions in Experiments 1, 2, and 4 quickly and robustly enhanced children's ability to incorporate the landmark into their search. First, the enhancement of performance relative to controls was as strong when the spatial expression occurred in Block 1 as in Block 2 (Experiments 1 and 2), indicating that children can construct a more appropriate construal of the landmark wall from the very first trial of the task. Second, the benefit of the spatial expression carried over from Block 1, when the expression was used on each trial, to Block 2, when the expression was no longer given, indicating that once children learn to construe a landmark appropriately they can maintain the altered representation without help, at least for the duration of the experimental session (Experiment 2). Third, a benefit was observed not only for hiding locations adjacent to the landmark wall but also for locations adjacent to the opposite wall, indicating that the expression enabled children's use of the red wall as an indirect landmark, not just as a direct marker of location (Experiments 1, 2, and 4). Fourth, in the condition where the red wall was mentioned in the expression but the hiding location was at the neutral wall (Experiment 4), the benefit was still observed, further supporting the claim that the verbal expression enhanced children's use of the distinctively colored wall as an indirect landmark.

Twyman et al. (2007) also have reported successful integration of the landmark in this paradigm, by children who received pre-training trials with the target location at the center of a yellow wall in an equilateral triangular array. Their finding demonstrates that non-linguistic experience can support children's attention to the landmark wall in the search task, as it does for animals (Gouteux et al., 2001). However, this type of experience may have more limited effects than the verbal cue presented here. Their study only used the two corners adjacent to the landmark wall as hiding locations. Thus, it is possible that children would not have been equally able to identify the target locations opposite from the red wall. The pre-training session could have taught the children to search *at the yellow wall*. Given how robustly children rely on room shape in this paradigm, children could use geometry to select the correct axis and associative mechanisms to learn that searching at the yellow wall is always rewarded.

Taken together, the present results suggest that semantic or pragmatic factors governing the interpretation of an utterance influence performance in reorientation tasks. If the language effects in the present studies were due to specific words or phrases, such as activation of the landmark concept RED WALL through activation of the words "red wall," then the different cue conditions should all have yielded a benefit. However, a benefit was not found for the cue that mentioned "red wall" but did not contextualize the landmark (Experiment 3). If language effects on navigation are due only to the syntactically mediated combination of the concepts like LEFT with concepts like RED WALL, then none of the cues should have yielded a strong benefit since none of them articulated "left." If language effects are due only to the presence of specifically spatial language, then only the cue used in the first two experiments ("at the red wall") should have yielded a benefit. Contrary to all these hypotheses, the results suggest that a critical role of language is to help the child construe the landmark as a cue to the position of the hidden object.

Children's failure to benefit from the verbal expression, "Look at the pretty red wall! I'm hiding the sticker here," is notable for a further reason. For adults, this expression likely would suggest that the red wall was relevant to the search task, through processes of pragmatic inference based on an assumption of communicative relevance (Grice, 1957; Sperber & Wilson, 1995). As in other studies of pragmatic inference (Huang & Snedeker, 2009), children in the present study did not seem to make the pragmatic inference that the experimenter's discussion of "the pretty red wall" was a hint to its usefulness in the task. Children evidently needed quite an explicit statement about the relation of the red wall to the task in order for them to use the experimenter's utterance as a guide to their task performance. In this respect, the present findings accord with evidence that children's mastery of natural language semantics outpaces their mastery of communicative pragmatics (Huang & Snedeker, 2009).

When a sufficiently explicit statement was made ("The red wall can help you find the sticker"), children were able to incorporate the red wall into their spatial reasoning without further instruction. This pattern of results suggests that 4-year-old children do not in principle have a problem using landmarks during disorientation; rather, they have a problem realizing that they *should* use the landmark to encode the position of the object before they are disoriented. As soon as they gain this realization, they exhibit competent search with respect to the red wall landmark in the rectangular room.

We suggest that semantics of the verbal cue influenced children's conceptual representation of the environment, and consequently their search behavior. However, the nature of this influence, and the properties of the resulting spatial representations, are open to varying interpretations. Indeed, the current studies demonstrate that language influences spatial representations, but they do not fully illuminate the mechanisms by which this happens or the exact reason why some cues were helpful while others were not. One possibility, suggested by Dessalegn and Landau (2008) is that language facilitates the binding of visual features like color and space. In their experiments, four-year-old children had to remember a visual target such as a square that was green on the left and red on the right. Telling children that "the red is to the left of the green" helped them to select the correct target object, but applying a label to the whole object or flashing one colored half of the square did not. Language tests revealed that children did not have stable knowledge of the words "left" and "right" nor did their linguistic knowledge correlate with their performance on the task. The authors conclude that directional language helps to bind spatial and non-spatial visual features for children, even when children cannot use the language fully to specify a location. Dessalegn and Landau's findings parallel those of the present experiments. Both sets of experiments show that children's visuospatial representations are enhanced by linguistic evidence, even when the language does not fully specify the spatial relation to be represented in a way that the child can interpret. Specifically, the current studies suggest that language can facilitate the binding of visual and spatial information as long as the visual information, i.e. color, is construed as relevant to the spatial task.

While the concept of binding is a useful one, it is somewhat underspecified. The linking of spatial and visual information in these tasks is not merely a conjunction of two features; rather, a colored object (a wall in our case, a half-square in Dessalegn and Landau) becomes interpreted as the Ground in a Figure-Ground relation. The Figure object is the hidden sticker in our case and the other colored half-square in Dessalegn and Landau. One role of language, then, may be to cast a feature of the environment, such as a colored wall, into the *semantic role* of "ground object" and into a corresponding *conceptual* role in spatial thought. This re-casting may then facilitate the computation and use of figure-ground relations in spatial behavior.

One puzzling question is why children used the spatial and task-relevant cues so easily, given that children rarely show this pattern in their spontaneous behavior. Four-year-old children may be on the cusp of developing good strategies for selecting appropriate frames of reference. By this age, they have good control over many spatial terms such as "front," "back," "above," and "below," incipient knowledge of words like "left" and "right," and the ability to mentally represent a variety of reference frames. Thus, our results might be particular to children who have already developed a fair amount of real-world and linguistic knowledge about spatial concepts. It is not clear whether the current performance patterns would be shown by younger children.

Three further points are worth noting. First, we observed an improvement in the control group between the first and second blocks of trials, based on the difference score measure.

Although the difference between blocks was not significant, children's performance was at chance in the first block but above chance in the second block; this pattern was seen for the unhelpful Mentioning expression in Experiment 3 as well. The improvement is predominantly due to the portion of children who had a neutral-wall target in the first block followed by a red-wall target in the second block. Thus, it seems that the contrast between the first and second block hiding locations helped children to focus in on the red wall.

Second, for the group as a whole, children were significantly more accurate when the hiding location was at the distinctive red wall than when it was at a non-distinct white or gray wall. These patterns are consistent with the idea that children used the red wall to mark location directly, and they suggest that the contrast between the two blocks of trials enhanced this ability. Surprisingly, the asymmetrical performance between locations at and away from the landmark wall has not been reported in most previous disorientation studies with children (Hermer & Spelke, 1994, 1996; Learmonth et al., 2001), perhaps because few studies have used the particular design employed here, with two blocks of trials with a constant hiding location within each block. Nevertheless, this trend is quite plain in our data and easily detected by collapsing across the experimental groups. Learmonth et al. (2008) also report that experience with the task helped three-year-olds in a large room to identify targets adjacent to the landmark (Learmonth et al., 2008), suggesting that experience with a landmark might enhance its use following disorientation.

Third, the presence of a verbal cue did not cause the children to drop their ability to use geometric information or to switch to a non-geometric pattern of error (e.g., searching at either side of the landmark wall). When children successfully used the landmark, they also responded in accord with the geometric properties of the room. Generally, the signature pattern revealing automatic use of geometry in this task is that errors cluster at the corner that is rotationally equivalent to the correct one. Because children made so few errors overall in the conditions where they succeeded in using the landmark, the signature error pattern is not detectable. Thus, these studies leave open the question of how, exactly, children solve the task.

One possibility is that children integrate their representations of the room geometry and the red wall. A second possibility is that children use these representations separately in a two-step process, first confining their choices to the two geometrically appropriate corners, then using the landmark to disambiguate them. Yet another possibility is that as soon as children come to use a landmark as a pointer to another location, they no longer need the geometric information; as long as they can orient by the landmark, they can appropriately choose whether an object is hidden to the left or right of it, regardless of wall length or room geometry. Furthermore, because the short neutrally colored wall is unique in the rectangular room with one short red wall, it is not clear whether children used a single landmark, the red wall, as a reference to all four hiding corners, or whether they used each short wall to locally mark the adjacent hiding corners. Further research should specifically test the effects of language on children's ability to incorporate landmarks into their representations in non-rectangular rooms that allow more refined tests of landmark use (Lee et al., 2006; Lourenco & Huttenlocher, 2006; Newcombe et al., 2009).

In summary, these experiments demonstrate that verbal cues dramatically enhance children's search following disorientation, supporting claims that language is related to the development of landmark use under disorientation. The findings accord with studies of adults, which show that encoding of significant locations in relation to environmental geometry occurs automatically, but that encoding of the same locations in relation to landmark objects requires the focusing effects of attention (Doeller & Burgess, 2008). Although language has multiple effects on spatial reasoning (Landau & Lakusta, 2009; Pyers et al., 2010), these findings reveal one such effect: language guides children's construal of landmarks as relevant for navigation. Future research should explore the extent to which this role of language helps to explain its capacity to influence both spatial and non-spatial thought.

References

Acredolo, L. P. (1978). Development of spatial orientation in infancy. *Developmental Psychology, 14*(3), 224-234.

Alerstam, T. (2006). Conflicting evidence about long-distance animal navigation. *Science, 313*(5788), 791-794.

Biegler, R., & Morris, R. G. M. (1996). Landmark stability: Studies exploring whether the perceived stability of the environment influences spatial representation. *Journal of Experimental Biology, 199*(1), 187-193.

Brown, A. A., Spetch, M. L., & Hurd, P. L. (2007). Growing in circles: Rearing environment alters spatial navigation in fish. *Psychological Science, 18*(7), 569-573.

Bushnell, E. W., McKenzie, B. E., Lawrence, D., & Connell, S. (1995). The spatial coding strategies of 1-year-old infants in a locomotor search task. *Child Development, 66*(4), 937-958.

Carruthers, P. (2005). Distinctively human thinking: Modular precursors and components. In P. Carruthers, S. Laurence & S. Stitch (Eds.), *The innate mind: Structure and contents* (pp. 69-88). Oxford: Oxford University Press.

Cheng, K., & Newcombe, N. S. (2005). Is there a geometric module for spatial orientation? Squaring theory and evidence. *Psychonomic Bulletin and Review, 12*(1), 1-23.

Dessalegn, B., & Landau, B. (2008). More than Meets the Eye: The Role of Language in Binding and Maintaining Feature Conjunctions. *Psychological Science*, *19*(2), 189-95.

Doeller, C. F., & Burgess, N. (2008). Distinct error-correcting and incidental learning of location relative to landmarks and boundaries. *Proceedings of the National Academy of Sciences, 105*(15), 5909-5914.

Doeller C.F., King J. A., & Burgess, N. (2008). Parallel and independent processing of environmental boundaries and landmarks in hippocampus and striatum. *Proceedings of the National Academy of Sciences, 105*(15), 5915-5920.

Dudchenko, P. A., Goodridge, J. P., Seiterle, D. A., & Taube, J. S. (1997). Effects of repeated disorientation on the acquisition of spatial tasks in rats: Dissociation between the appetitive radial arm maze and aversive water maze. *Journal of Experimental Psychology: Animal Behavior Processes, 23*(2), 194-210.

Frank, M., Gibson, E., Fedorenko, E., & Everett, D. (2008). Number as a cognitive technology: Evidence from Pirahã language and cognition. *Cognition, 108*(3), 819-824.

Gallistel, C. R. (1990). *The organization of learning*. Cambridge, MA: MIT Press, Bradford Books.

Geary, D. C., Saults, S. J., Liu, F., & Hoard, M. K. (2000). Sex differences in spatial cognition, computational fluency, and arithmetical reasoning. *Journal of Experimental Child Psychology, 77*(4), 337-353.

Gouteux, S. & Spelke, E. S. (2001). Children's use of geometry and landmarks to reorient in an open space. *Cognition, 81*(2), 119-148.

Gouteux, S., Thinus-Blanc, C., & Vauclair, J. (2001). Rhesus monkeys use geometric and nongeometric information during a reorientation task. *Journal of Experimental Psychology: General, 130*(3), 505-519.

Grice, P. (1957). Meaning. *The Philosophical Review, 66*(3)*,* 377-388.

Haun, D. B. M., Rapold, C., Call, J., Janzen, G., & Levinson, S. C. (2006). Cognitive cladistics and cultural override in Hominid spatial cognition. *Proceedings of the National Academy of Sciences, 103*(46), 17568-17573.

Hermer-Vasquez, L., Moffet, A., & Munkholm, P. (2001). Language, space, and the development of cognitive flexibility in humans: the case of two spatial memory tasks. *Cognition, 79*(3), 263-299.

Hermer-Vasquez, L., Spelke, E. S., & Katsnelson, A. S. (1999). Sources of flexibility in human cognition: Dual-task studies of space and language. *Cognitive Psychology, 39*(1), 3-36.

Hermer, L., & Spelke, E. S. (1994). A geometric process for spatial reorientation in young children. *Nature, 370*(6484), 57-59.

Hermer, L., & Spelke, E. S. (1996). Modularity and development: The case of spatial reorientation. *Cognition, 61*(3), 195-232.

Hoyos, C., Nuzzi, L., & Shusterman, A. (2011, March). *Left-right language predicts children's landmark use in a disorientation task.* Presented at the Biennial Meeting of the Society for Research on Child Development, Montreal, QC, Canada.

Huang, Y. T., & Snedeker, J. (2009). Semantic meaning and pragmatic interpretation in five-year olds: Evidence from real time spoken language comprehension. *Developmental Psychology, 45*(6)*,* 1723-1739.

Hupbach, A., Hardt, O., Nadel, L., & Bohbot, V. (2007). Spatial reorientation: Effects of verbal and spatial shadowing. *Spatial Cognition and Computation, 7*(7), 213-226.

Knierim, J. J., Kudrimoti, H. S., & McNaughton, B. L. (1995). Place cells, head direction cells, and the learning of landmark stability. *Journal of Neuroscience, 15*(3, Pt 1), 1648-1659.

Lakusta, L., Dessalegn, B., & Landau, B. (2010). Impaired geometric reorientation caused by genetic defect*. Proceedings of the National Academy of Sciences, 107*(7)*,* 2813-2817.

Landau, B. & Lakusta, L. (2009). Spatial representation across species: geometry, language, and maps. *Current Opinion in Neurobiology, 19*(1), 12019.

Learmonth, A. E., Nadel, L., & Newcombe, N. S. (2002). Children’s use of landmarks: Implications for modularity theory. *Psychological Science, 13*(4), 337-341.

Learmonth, A. E., Newcombe, N. S., & Huttenlocher, J. (2001). Toddler’s use of metric information and landmarks to reorient. *Journal of Experimental and Child Psychology, 80*(3), 225-244.

Learmonth, A. E., Newcombe, N. S., Sheridan, N., & Jones, M. (2008). Why size counts: Children’s spatial reorientation in large and small enclosures. *Developmental Science, 11*(3), 414-426.

Lee, S. A., Shusterman, A., & Spelke, E. (2006). Reorientation and landmark-guided search in children: Evidence for two systems. *Psychological Science, 17*(7), 577-582.

Lee, S. A., & Spelke, E. S. (2010). A modular geometric mechanism for reorientation in children. *Cognitive Psychology, 61*(2), 152-176.

Lever, C., Wills, T., Cacucci, F., Burgess, N., & O'Keefe, J. (2002). Long-term plasticity in hippocampal place-cell representation of environmental geometry. *Nature, 416*(6876), 90-94.

Lew, A. R., Foster, K. A., & Bremner, J. G. (2006). Disorientation inhibits landmark use in 12-18-month-old infants. *Infant Behavior and Development, 29*(3), 334-341.

Lourenco, S., & Huttenlocher, J. (2006). How do young children determine location? Evidence from disorientation tasks. *Cognition, 100*(3), 511-529.

Lourenco, S., & Huttenlocher, J. (2007). Using geometry to specify location: Implications for spatial coding in children and nonhuman animals. *Psychological Research, 71*(3), 252-264.

Muheim, R., Phillips, J. B., & Åkesson, S. (2006). Polarized light cues underlie compass calibration in migratory songbirds. *Science, 313*(57), 837-839.

Nardini, M., Atkinson, J., & Burgess, N. (2008). Children reorient using the left/right sense of coloured landmarks at 18-24 months. *Cognition, 106*(1), 519-527.

Newcombe, N. S., Ratliff, K. R., Shallcross, W., & Twyman, A. D. (2009). Young children's use of features to reorient is more than just associative: Further evidence against a modular view of spatial processing. *Developmental Science, 13*(1), 213-220.

O'Keefe, J., & Burgess, N. (1996). Geometric determinants of the place fields of hippocampal neurons. *Nature, 381*(6581), 425-428.

Pyers, J., Shusterman, A., Senghas, A., Emmorey, K., & Spelke, E. S. (2010). Evidence from an emerging sign language reveals that language supports spatial cognition. *Proceedings of the National Academy of Sciences, 107*(27)*,* 12116-12120.

Ratliff, K.R., & Newcombe, N.S. (2008a). Reorienting when cues conflict: Using geometry and features following landmark displacement. *Psychological Science, 19*(12), 1301-1307.

Ratliff, K. R., & Newcombe, N. S. (2008b). Is language necessary for human spatial reorientation? Reconsidering evidence from dual task paradigms. *Cognitive Psychology, 56*(2), 142-163.

Shusterman, A., & Spelke, E. S. (2005). Language and the development of spatial reasoning. In P. Carruthers, S. Laurence & S. Stich (Eds.), *The innate mind: Structure and Contents* (pp. 89-108). Oxford: Oxford University Press.

Sovrano, V. A., Bisazza, A., & Vallortigara, G. (2002). Modularity and spatial reorientation in a simple mind: Encoding of geometric and nongeometric properties of a spatial environment by fish. *Cognition, 85*(2), 51-59.

Spelke, E. S. (2003). What makes us smart? Core Knowledge and natural language. In D. Gentner & S. Goldin-Meadow (Eds.), *Language in mind: Advances in the study of language and thought*. Cambridge, MA: MIT Press.

Spelke, E. S., & Tsivkin, S. (2001). Language and number: A bilingual training study. *Cognition, 78*(1), 45-88.

Sperber, D. & Wilson, D. (1995). *Relevance: Communication and cognition* (2nd ed.) Oxford: Blackwell.

Sutton, J. E. (2006). The development of landmark and beacon use in young children: Evidence from a touchscreen search task. *Developmental Science, 9*(1), 108-123.

Sutton, J. E., Joanisse, M. F. & Newcombe, N. S. (2010). Spinning in the scanner: Neural correlates of virtual reorientation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36*(5)*,* 1097-1107.

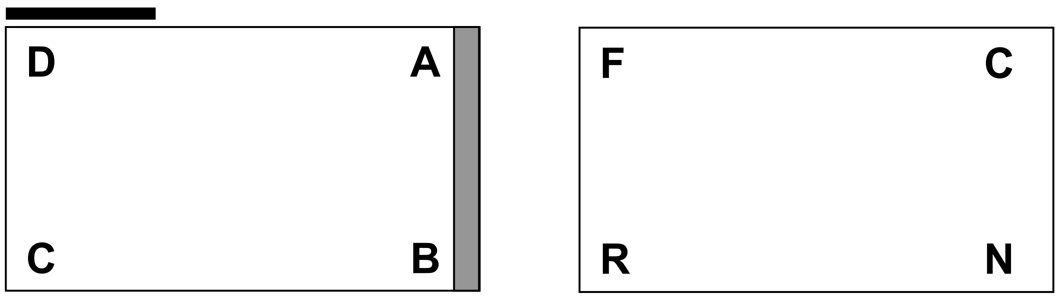
Tommasi, L., & Thinus-Blanc, C. (2004). Generalization in place learning and geometry knowledge in rats. *Learning and Memory, 11*(2), 153-161.

Twyman, A., Friedman, A., & Spetch, M. L. (2007). Penetrating the geometric module: Catalyzing children's use of landmarks. *Developmental Psychology, 43*(6), 1523-1530.

Twyman, A. D., & Newcombe, N. S. (2010). Five reasons to doubt the existence of a geometric module. *Cognitive Science, 34*(7), 1315-1356.

Wang, R. F., Hermer, L., & Spelke, E. S. (1999). Mechanisms of reorientation and object localization by children: A comparison with rats. *Behavioral Neuroscience, 113*(3), 475-485.

Waxman, S. R., & Markow, D. B. (1995). Words as invitations to form categories: Evidence from 12- to 13-monthold infants. *Cognitive Psychology, 29*(3), 257-302.



(a) (b)

Figure 1. (a) Layout of experimental apparatus and hiding corners A, B, C, and D. Gray bar indicates location of red wall. Black bar indicates location of hidden door. (b) Depiction of possible search locations. C: correct; N: near; R: rotated; F: far. Data from all four possible hiding places are rotated to this format. If B was the target hiding location, search at B would be correct, search at A would be a near error, search at D would be a rotational error, and search at C would be a far error.

Figure 2. Results from Experiment 1. Starred corner indicates search at the correct corner (C). All data are rotated to the format indicated in the upper left hand box, with numbers indicating mean percent of searches at correct location (C), rotational error (R), near error (N), and far error (F). The numbers in the center of each diagram are mean difference scores (C-R) and standard deviations. Asterisks (*) indicate difference scores significantly above zero (* $p < .05$, ** $p < .01$). Numbers in bold type indicate significantly more correct search in the experimental group relative to controls.

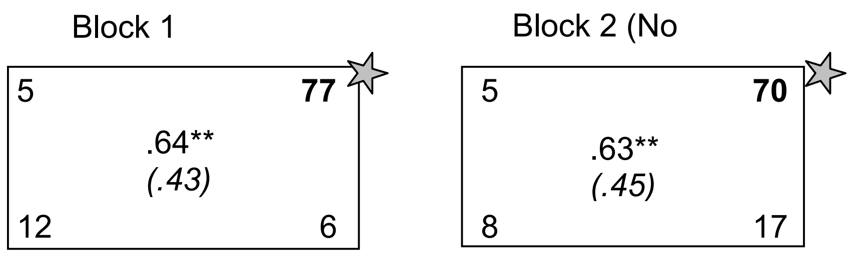


Figure 3. Results from Experiment 2, with a spatial expression given in Block 1. Starred corner indicates search at the correct corner. All data are rotated accordingly, with numbers indicating mean percent of searches at each location. Numbers in bold type indicate significantly more correct search in the experimental group relative to Experiment 1 controls.

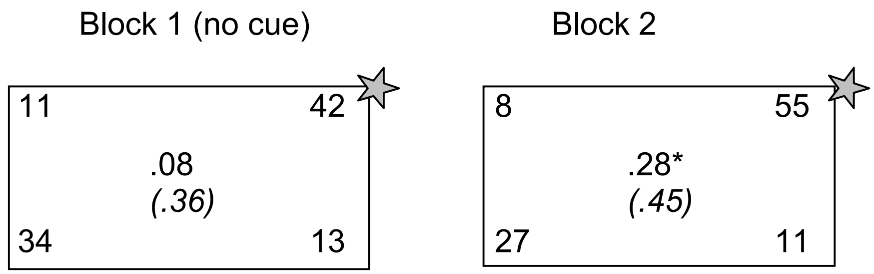


Figure 4. Results from Experiment 3, with a Mentioning expression given in Block 2. Starred corner indicates search at the correct corner. All data are rotated accordingly, with numbers indicating mean percent of searches at each location.

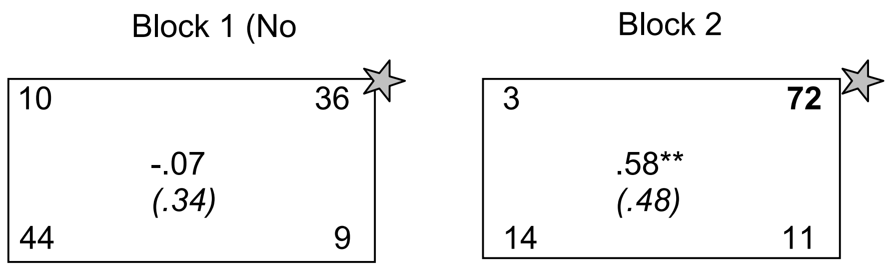


Figure 5. Results from Experiment 4, with Relevant expression given during Block 2. Numbers in bold type indicate significantly more correct search in the experimental group relative to Experiment 1 controls.

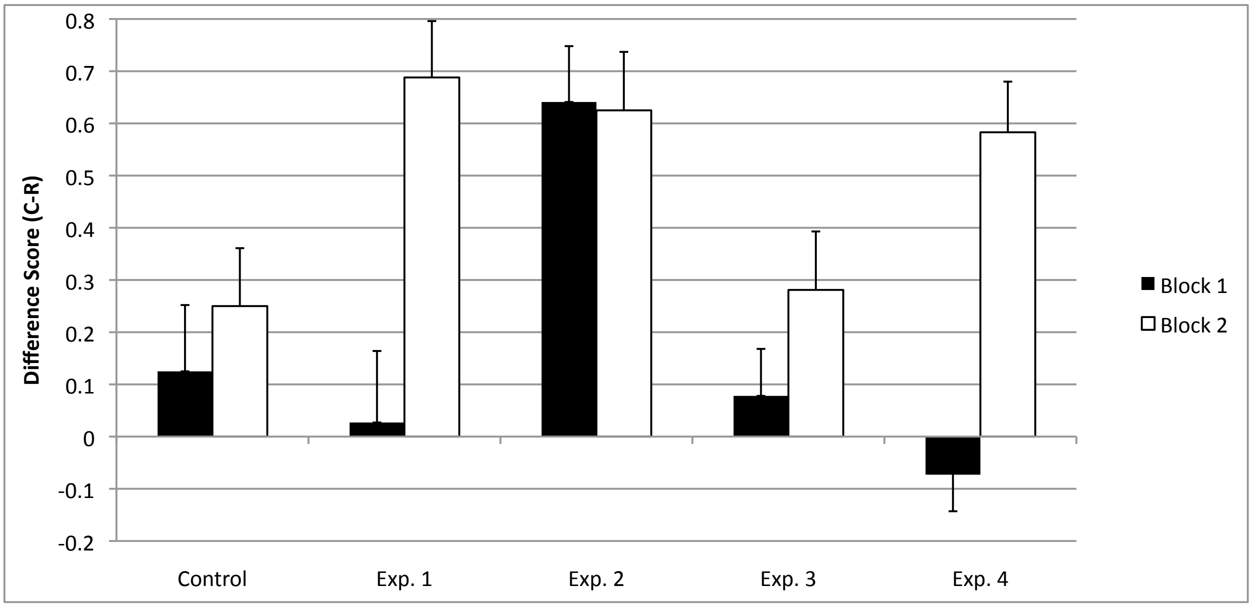


Figure 6. Results from Experiments 1-4, showing C-R difference scores (Mean ± SEM).

Table 1. Mean difference scores (C – R) separated by whether target location was at the red wall landmark (Red) or at the short neutral wall (Neutral). Bold type indicates a significant effect of wall color for Experiment 3 and for combined group overall (*p* < .05).

	Block 1		Block 2	
	Red	Neutral	Red	Neutral
Control	.25	.00	.41	.09
Exp 1	.19	-.13	.78	.47
Exp 2	.69	.59	.69	.69
Exp 3	-.06	.22	**.50**	**.06**
Exp 4	-.06	-.09	.75	.50
Overall	.16	.12	**.63**	**.39**