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Research Article

Spatial Language and Children's Spatial Landmark Use

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We examined how spatial language affected search behavior in a landmark spatial search task. In Experiment 1, two- to six-year-old children were trained to find a toy in the center of a square array of four identical landmarks. Children heard one of three spatial language cues once during the initial training trial ("here," "in the middle," "next to this one"). After search performance reached criterion, children received a probe test trial in which the landmark array was expanded. In Experiment 2, two- to four-year-old children participated in the search task and also completed a language comprehension task. Results revealed that children's spatial language comprehension scores and spatial language cues heard during training trials were related to children's performance in the search task.

1. Introduction

Adults are extremely adept at using landmarks to navigate space (e.g., turn left at the gas station) and to remember the location of objects (e.g., the keys are between the vase and the lamp). Yet what is easy for adults is difficult for young children. Children's ability to use landmarks develops slowly throughout the preschool years [1, 2]. During this time, children's ability to use spatial language also develops (e.g., "by," "middle") [3, 4]. The current study examines how these processes mutually influence one another by investigating how spatial language contributes to spatial learning. We examine this relationship by: (1) analyzing whether comprehension of spatial words is related to search behavior and (2) analyzing how search behavior is affected by spatial language cues. We focus our examination on the spatial concept of "middle." Middle is a particularly challenging spatial concept because it requires children to estimate location equidistant from multiple landmarks.

2. The Development of Children's Landmark Use

A central task in the development of spatial cognition is to learn to use objects as landmarks for another object's location. Initially, children's ability to use landmarks is limited, but the ability to use single and then multiple landmarks becomes gradually more sophisticated. Children learn to use single landmarks before using multiple landmarks in conjunction [2]. During the first year of life, children begin to use single landmarks as direct markers, or beacons, of an object's location (the cookie is *in* the cookie jar) [5–8]. Children later learn to use single landmarks as indirect markers of an object's location (the cookie is *next to* the cookie jar) [2, 9]. For example, Plumert and Hawkins [9] asked children to find a toy in either a direct landmark condition (e.g., "the toy is *in* the chair") or an indirect landmark condition (e.g., "the toy is *next to* the chair"). Three-year old children found the toy significantly faster in the direct landmark condition. Still a more complex way of using landmarks is to attend to the relation between multiple landmarks (e.g., the cookie is *between* the cookie jar and the blender). Using landmarks relationally requires calculating the location of an object in relation to multiple referents, a task that, like other relational tasks in the preschool years [10–12], poses a greater challenge to children than locating an object in regard to a single referent.

Typically, children do not use multiple landmarks to find a hidden object until well into their preschool years [13–15]. However, there is debate regarding at what age children acquire the ability to do so [15, 16]. In some studies, by the age of four or five years old children readily use multiple landmarks to find a hidden object [13, 15]. In other studies, four- and five-year old children fail to use multiple landmarks to find a hidden object when other methods of solving the task are possible [16]. Contradictory accounts regarding the timing of relational landmark development may suggest that children's performance is related to task-specific factors (e.g., some studies used two landmarks while others used four landmarks, some studies used an open field while other studies used a small box, etc.), or that children may favor solutions that allow attention to only one landmark when available.

Nonhuman animals also appear not to use multiple landmarks relationally [16–19]. In expansion tasks in which animals were first trained to search in the center of an array of landmarks followed by a test trial in which the landmarks were expanded, gerbils [18], pigeons [20], and primates [16, 21, 22] did not search relationally (i.e., in the center of the expanded landmark array). Instead, these species tended to search at a discrete distance and direction from one of the landmarks in the array. Though some species (e.g., Clark's nutcrackers) have been trained to use a relational strategy when a task cannot be solved in other ways [19], nonhuman animals do not readily use multiple landmarks relationally when other methods of solving the task are available [16].

The data from nonverbal animals and young children support one possible explanation for children's struggles with relational encoding at this age. It is possible that learning spatial words helps children to solve spatial landmark tasks. The current study examined how the development of spatial language relates to children's performance in relational landmark tasks. We focused on the relationship between the spatial relational word "middle" and children's ability to use the middle relation in a spatial search task, because the middle relation may be particularly challenging to children. First, middle is a viewpoint-independent term [1]. Unlike egocentric (e.g., left) or allocentric (e.g., north) spatial terms, the word "middle" does not have a reliable, unchanging referent. Instead, the word "middle" is used flexibly to refer to the relationship between any object and any of multiple landmarks of any distance apart from one another. Second, identifying the middle of multiple landmarks requires estimating distances with a fair degree of accuracy (but see [23], for a perceptual alternative used by honeybees). Previous research suggests that in nonsearch tasks in which children are habituated to spatial relationships between objects, children as young as six months old can categorize based on the *between* relation when distance calculation is not a factor [24, 25]. Yet unlike the *between* spatial relation, the *middle* relation requires children to attend to the precise distance between landmarks, which may be more challenging to children. Third, the word "middle" commonly appears in both spatial contexts (e.g., the location equidistant from multiple landmarks) and nonspatial contexts (e.g., the second of three children). Even when the word "middle" is used in a spatial context, it is often inexact. For example, phrases such as "standing in the middle of the room" only rarely indicate standing in the precise location that is equidistant from each corner of the room.

3. Spatial Language Comprehension

Children's experience with language is temporally linked with their understanding of associated concepts in the same domain [26, 27]. For example, children's acquisition of disappearance words (e.g., "gone") corresponds with their emerging skills in object permanence tasks and children's acquisition of success/failure words (e.g., "there," "uh-oh") corresponds with their emerging skills in means-end tasks [27]. Cross-cultural research shows similar ties between language experience and cognition, revealing that children develop early cognitive skills associated with word types emphasized in their native languages. For example, Korean-speaking children tend to acquire verbs earlier in language development than English-speaking children, and English-speaking children tend to acquire nouns earlier than Korean-speaking children [28–31]. Korean-speaking children also show earlier skill in verb-related means-end tasks, whereas English-speaking children show earlier skill in noun-related categorization tasks [30, 32].

Similar findings in the domain of space indicate strong ties between spatial language and spatial reasoning [26, 33]. For example, the different ways in which spatial terms are used across languages result in children's development of very different spatial categories according to the conventions of their native language [26]. Such findings have led some researchers to argue that the development of spatial language and the development of spatial cognition mutually influence one another.

Although the precise mechanisms by which spatial language and spatial cognition develop are unknown, they appear to mutually affect one another in studies of infant spatial category recognition [26, 34, 35]. By eighteen months old, children identify language-specific spatial relationships [26, 35], suggesting that spatial language input helps to construct and order children's view of space from very early in development. Casasola et al. [34] further showed that even minimal exposure to spatial language influences children's perception of spatial relationships. English-speaking children were familiarized to a novel spatial relation (i.e., the tight-fit relation) with or without a novel word. Only children who saw the spatial relation paired with the novel word learned to distinguish the tight-fit spatial relation from a contrasting loose-fit spatial relation. Because spatial language influences the way that children perceive spatial relationships, learning the word "middle" may result in a greater ability to use the middle spatial relation and thus lead to more middle search behavior in the current studies.

Other studies, however, suggest that comprehension of the term "middle" and nonverbal performance with the spatial concept may not be so closely related. In a study of English-speaking preschool-aged children, Loewenstein and Gentner [4] found that 84% of three-year old children and 100% of four-year old children comprehended the word "middle" in a spatial search task. Even though three and four year old children comprehend the word "middle," however, children at these ages (and older) do not consistently use the middle relation in spatial search tasks when other methods of solving the spatial task are available [16]. Even after the term "middle" enters children's comprehensive vocabularies, children may not apply the concept to a spatial search task when the task can be solved in simpler ways (i.e., searching a discrete distance and direction from a single landmark).

4. Spatial Language Cues

Experimenter-provided language cues can also affect children's performance during a task. In categorization studies, labeling objects during the task facilitates categorization by heightening attention to similarities between objects and aggregating discrete instances [10, 36–41]. Language cues may be particularly important for facilitating children's relational reasoning, because children show substantial difficulty acquiring relational categories across domains [11]. Unlike categories (e.g., object categories) that are defined by static, shared perceptual features, members of relational categories share little perceptual similarity. For example, there is little perceptual similarity between the middle relation depicted by a house in the *middle* of two hills and a book on the *middle* shelf in a stack of shelves. Multiple studies indicate that children match objects based on salient perceptual features well before they match objects based on relational information (see [11] for a review). Because of the lack of shared perceptual similarity between different instances of *middle*, language cues may be particularly important for helping children detect and use middle spatial relations.

5. The Current Studies

The current studies investigated the relationship between children's acquisition of the term "middle" and their performance in a landmark task. We chose a landmark task with multiple solutions (i.e., using multiple or single landmarks), and examined how comprehension of the spatial word "middle" related to use of a single-landmark strategy versus a multiple-landmark strategy. We used a modified version of MacDonald et al.'s [16] task, in which children were trained to find a goal in the center of a square array of four identical landmarks (see Figure 1(a)). After performance reached criterion, children were given a probe test trial in which the landmark array was expanded (see Figure 1(b)). There were two ways for children to approach the spatial task. For example, children could search at a location equidistant from each of the four landmarks in the expanded array (middle search), as adult humans do. Alternatively, children could search at the same absolute distance and direction from a single landmark in one of the four corners of the expanded array (corner search), as nonhuman animals do. Children could also exhibit other search behavior, including searching in random locations in or outside of the landmark array, or could fail to reach criterion for the expanded test trial. We examined whether children's comprehension of the spatial word "middle" and children's search behavior were related. Finally, we examined how different spatial word primes affected children's search behavior.

6. Experiment 1

6.1. Method

6.1.1. Participants. Thirty-six children completed the experiment (mean age = 54.4 months, SD= 16.36, range: 24.1–82.9 months): five two-year olds (mean age = 30.32 months, SD = 2.08, range: 24.1–34.4 months), nine three-year olds (mean age = 41.94 months, SD = 1.55, range: 36.9–45.1 months), seven four-year olds (mean age = 53.1 months, SD = 1.76, range: 48.1–57.1 months), nine five-year olds (mean age = 65.8 months, SD = 1.55, range: 61.1–71.9 months), and six six-year olds (mean age = 77.57 months, SD = 1.9, range: 72.5–82.9 months). All children were from native English-speaking households. An additional six children were excluded for failure to meet test criterion (mean age = 21.47 months, SD = 5.66, range: 13.2–28.8 months).

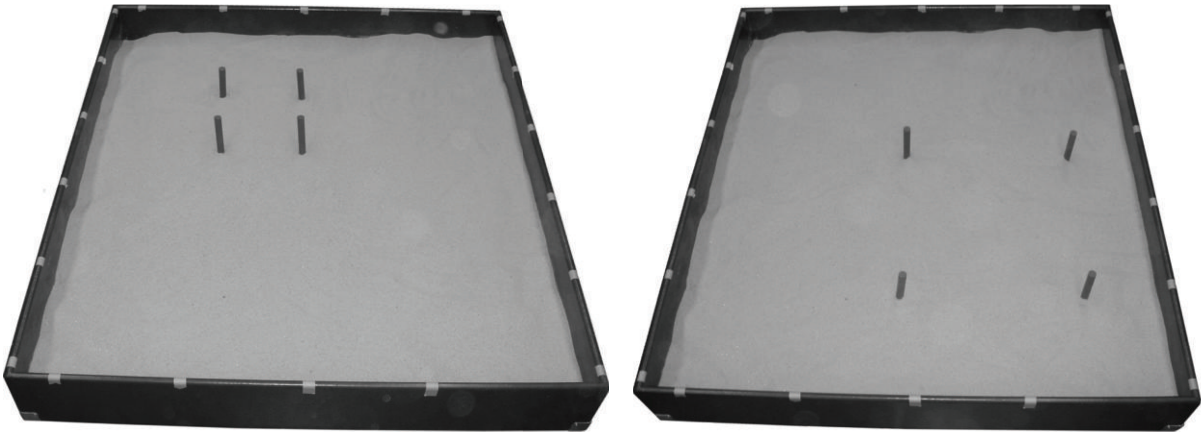
6.1.2. Materials and Apparatus. Figure 1 shows the 1.2×1.4 m sandbox custom-made for this study. The sandbox was placed in the center of a well-lit, 5.8×6.2 m classroom containing twelve standard classroom desks and a whiteboard. An overhead camera was positioned directly over the sandbox to record each trial. The walls of the sandbox were 15.2 cm high and contained approximately 8 cm of standard white sand. The bottom of the sandbox was raised 10 cm above the floor. The sandbox was dark brown and small pieces of masking tape were placed along its edge at 25 cm intervals, marking predetermined locations at which landmark arrays were placed during the experiment.

Eight identical blue wooden posts, each 2.5 cm in diameter and 15 cm in length served as landmarks. Four landmarks were configured into a 25×25 cm square array (Figure 1(a)), and the other four were configured into a 50×50 cm square array (Figure 1(b)). Wooden dowels (0.6 cm diameter) connecting the bottom of the landmarks held each array together. When placed in the sandbox, the bottom of the landmark array was buried 5 cm below the sand, leaving 10 cm of each blue post exposed above the sand. A 2.5×3.8 cm plastic toy monkey was used as the goal during cued and uncued training trials. During these trials, the monkey was hidden about 2.5 cm below the sand.

A parent questionnaire was used to assess children's spatial vocabularies, which included a list of spatial relational terms (e.g., "middle," "center," "by" and "near") and questions regarding children's experience with books, games and other activities in which they may have used spatial concepts (e.g., "Have you read any books to your child that may have taught him or her spatial concepts such as "middle"?").

6.1.3. Design. Children were divided into one of three between-subjects language conditions: (1) control, (2) "next to," and (3) "middle."

In order to preserve procedural details from MacDonald et al. [16], half of the children in this study heard three cued training trials. To investigate whether multiple-cued training trials influenced children's search behavior, the other half of children heard only one cued training trial. Children were



(a) (b)

Figure 1: Pictures of the small and large landmark arrays in the sandbox. (a) shows the training landmark array and (b) shows the expanded landmark array.

assigned to one versus three training trials equally according to age and language condition.

6.1.4. Procedure. The experiment consisted of three phases: (1) cued training trials, (2) uncued training trials, and (3) expanded test trial. During each trial, Experimenter 1 placed landmark arrays in randomized predetermined locations, which corresponded with grid locations created by masking tape placed on the sides of the sandbox at 25 cm intervals (Figure 1). Twenty locations were possible for the small (nonexpanded) landmark array and 12 locations were possible for the large (expanded) landmark array. Landmark locations were randomly assigned per trial for each child, so no two children saw the same sequence of hiding locations. Experimenter 1 also hid the toy and timed children while they searched. Experimenter 2 distracted children and ensured that they did not observe the sandbox between trials. Because children had the option to dig from either inside or outside of the sandbox, Experimenter 2 also helped children into the sandbox when needed.

Cued Training Trials. Cued training trials served as instruction for children, allowing children to watch the object being hidden so that they would know where to retrieve it on subsequent uncued trials. Children experienced either one or three cued training trials. During these trials, children watched as Experimenter 1 hid the toy in the center of the small landmark array by pressing the toy into the sand and brushing the sand to smooth it over. Children also heard one of three language cues. Children in the control condition heard, "I am hiding the toy *here*." Children in the "next to" condition heard, "I am hiding the toy *next to this one*." Children in the "middle" condition heard, "I am hiding the toy *in the middle*." Children were given ten seconds to find the toy. If they did not do so, the experimenter uncovered the toy for the child to retrieve.

Uncued Training Trials. During uncued training trials, Experimenter 1 placed the small landmark array in a randomized predetermined location and hid the toy in the center of the landmark array while Experimenter 2 distracted the child. Children were then asked to find the toy (i.e., "The toy is hidden. Can you find it?"), but no other language cues were provided. If children retrieved the toy within ten seconds on three consecutive trials, they advanced to the test trial. Children who reached twenty trials without finding the toy within ten seconds on three consecutive trials were excluded from the experiment.

Expanded Test Trial. During the expanded test trial, Experimenter 1 placed the large landmark array in a randomized, predetermined location, while Experimenter 2 distracted the child. Children were told to look for the toy, but there was, in fact, no toy present. Children were given ten seconds to search after which the trial was terminated.

Experimenters 1 and 2 independently charted children's initial search locations. Children were also filmed during the task. For data analysis, children's search locations were determined by overhead camera footage. Children's searches were coded in two ways. First, children's searches were coded for their distance from the center of the expanded landmark array. Second, children's searches were coded as being in middle, corner, or other regions of the landmark array. Figure 2 depicts five 12.7 cm regions representing possible search locations (one center "middle" location and four "corner" locations).These locations were based on hypothetical search strategies. The middle location was determined based on the search strategy used by adults in this task [16], in which adults calculate the middle of the expanded landmark array. The corner locations were determined based on the search strategy used by pigeons and other nonverbal animals in this task [16], in which animals search the same distance and direction from a single landmark as the goal had been in the nonexpanded landmark array. Two independent coders judged the videotapes for children's initial search locations,

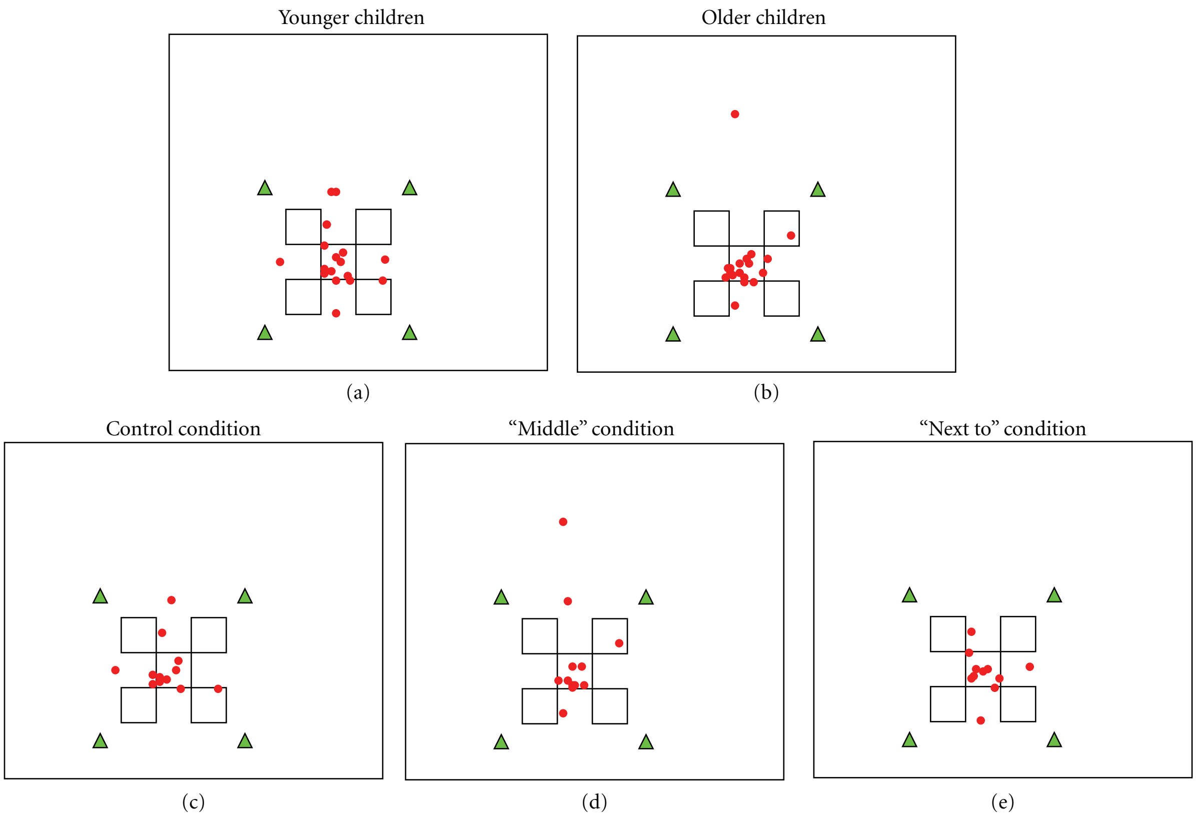


Figure 2: Experiment 1: Plots of children's initial search location during the expanded test trial by age group and language condition. Search locations are plotted according to age (younger children: $n = 18$, M age = 40.65 months, SD = 8.73, range: 24.1–54.6 and older children: $n = 18$, M age = 68.15 months, SD = 8.63, range: 55.4–82.9) and language condition (control, "middle", and "next to").

with 100% agreement between coders regarding the regions of children's searches (middle, corner, other). If children's search locations were not discernible from video footage or if footage was not available ($n = 4$), an average of the charted locations captured from the two experimenters was used to determine the child's search location. If there was disagreement between the two experimenters regarding the search location (middle, corner, other) of a child who was not videotaped, the child would be excluded from the study ($n = 0$).

6.2. Results and Discussion

6.2.1. Training Trials. Results revealed no effects of whether children were exposed to one or three cued training trials. There was no difference in the number of uncued training trials that children required ($F(1, 34) = .15$, $P = .7$, $\eta^2 = .004$) according to the number of cued training trials they heard. There was also no difference in the number of children who searched in the middle region of the landmark array ($\chi^2(1, N = 36) = .18$, $P = .67$) or in the distance children searched from the center of the landmark array ($F(1, 34) = .04$, $P = .85$, $\eta^2 = .00$) according to whether they experienced one ($M = 9.06$, SD = 7.19) or three ($M = 9.67$, SD = 10.99) cued training trials. Thus, we collapsed across this variable for the remainder of the analyses.

There was no effect of age ($F(1, 31) = .62$, $P = .65$, $\eta^2 = .07$) or gender ($F(1, 34) = .69$, $P = .41$, $\eta^2 = .02$) on the number of uncued training trials children required. On average, children required 4.97 uncued training trials to meet criterion (SD = 3.81).

6.2.2. Expanded Test Trials. Across all three language conditions, most children searched in the middle region of the expanded landmark array. Figure 2 depicts five 12.7 cm regions representing possible search locations (one center "middle" location and four "corner" locations). Chi-square analysis revealed that more children searched in the center of the expanded landmark array than searched in any other location, ($\chi^2(1, N = 36) = .16.67$, $P = .00$). Combining all three of the language-cued conditions revealed that overall 61% of children searched in the middle region of the landmark array. Only 6% of children searched in the corners of the array. The remaining 33% of children searched in locations outside of the five designated possible target regions. Of these children, only one child searched outside of the expanded landmark array. We additionally coded the distance of children's searches from the center of the landmark array. This analysis revealed that across ages and language conditions, children searched an average of 9.36 cm (SD = 9.16) from the center of the landmark array.

Across conditions, children's search strategies were not significantly related to children's age. A median split by age revealed that 67% of older children ($n = 18$, M age = 68.15 months, SD = 8.63, range: 55.4–82.9) across conditions searched in the middle, and 56% of younger children ($n = 18$, M age = 40.65 months, SD = 8.73, range: 24.1–54.6) searched in the middle, $\chi^2(1, N = 36) = .47$, $P = .49$. Analyses on distance from middle yielded similar results. An ANOVA revealed that the distance from children's searches to the center of the landmark array did not differ by whether children were from younger ($M = 10.06$, SD = 7.16) or older ($M = 8.67$, SD = 10.98) age groups, $F(1, 34) = .20$, $P = .66$, $\eta^2 = .01$. There was no correlation between the distance that children searched from the center of the array and age in months ($r = -.17$, $P = .33$) or age in years ($r = -.11$, $P = .53$). Unlike previous research citing sex differences in young children's use of landmarks [14], we did not find differences in girls' and boys' search locations ($\chi^2(1, N = 36) = .33$, $P = .56$) or in the distance that boys ($M = 7.47$, SD = 5.73) and girls ($M = 10.71$, SD = 10.92) searched from the center of the landmark array ($F(1, 34) = 1.10$, $P = .30$, $\eta^2 = .03$).

6.2.3. Spatial Language Cues. When children of all ages were combined, language cues appeared to have little effect on children's search strategies. The number of children who searched in the middle of the landmark array did not differ by language condition, $\chi^2(1, N = 36) = .94$, $P = .63$. Of children in the control language condition, 50% searched in the middle, 8% searched in a corner, and the remaining 42% searched in other locations. Of children in the "next to" condition, 67% searched in the middle, 0% searched in a corner, and the remaining 33% searched in other locations. Of children in the "middle" condition, 67% searched in the middle, 8% searched in a corner, and the remaining 25% searched in other locations. The distance that children searched from the center of the array also did not differ according to whether children heard a "middle" ($M = 11.50$, SD = 13.53), "next to" ($M = 7.42$, SD = 5.35) or control ($M = 9.17$, SD = 6.79) language cue, $F(2, 33) = 59$, $P = .56$, $\eta^2 = .03$. Overall, children's tendency to use a middle search strategy did not differ by language condition; however, analysis of individual language conditions revealed that middle language cues may have facilitated younger children's performance.

As Figure 3 shows, children in the control condition who were not prompted with a spatial language cue appeared to show increases with age in middle searches. Although 0% of two-year olds searched in the middle, 100% of six-year olds did, and by six years old children performed equivalently to adults in the same procedure [20, 42]. Performance in the "middle" and "next to" conditions, however, appeared more varied across ages.

The results of the "middle" condition suggest that prompting children with relational language may have helped younger children ($n = 18$, M age = 40.65 months, SD = 8.73, range: 24.1–54.6), but not older children ($n = 18$, M age = 68.15 months, SD = 8.63, range: 55.4–82.9) to employ a middle search strategy. A median split by children's age revealed that 80% of younger children in the "middle" language condition searched in the middle region, but less than 60% of younger children in the control or "next to" language conditions did so (Figure 4). Hearing the term "middle" did not have the same effect on older children's searches. Instead, across conditions, most older children searched in the middle of the array regardless of the language cue they heard during the experiment. Hearing relational language may not have affected older children's performance because their performance was at ceiling regardless of language condition. Older children may have been able to

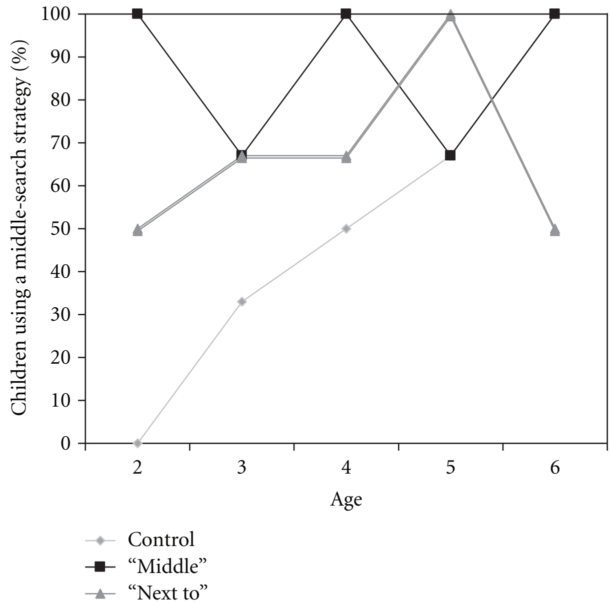


Figure 3: Experiment 1—percentage of middle searches by age and condition.

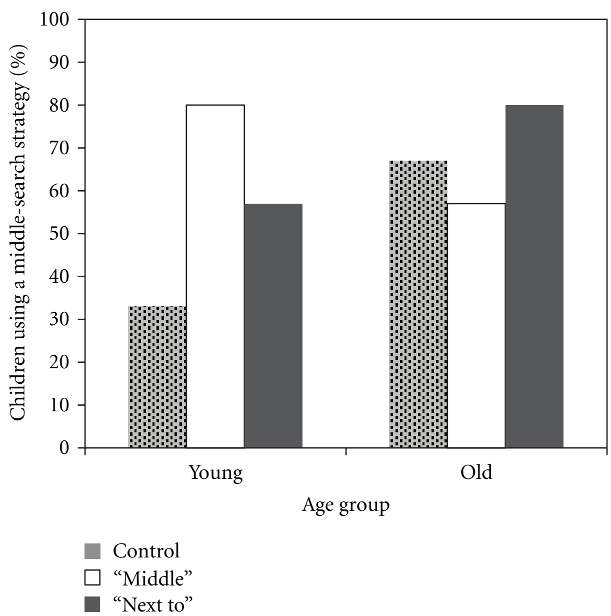


Figure 4: Experiment 1—percentage of middle searches by age group and language condition.

perceive and act on the middle relation without the aid of language (due to their preexisting knowledge). However, the tendency for young children to search in the middle appeared to be facilitated by spatial language cues. This finding is especially striking because half of these children heard the language cue only once. However, the sample of young children in this study was too small to determine statistical significance. Because of this, Experiment 2 focused on the younger ages of two to four years old to better examine how language cues affect search behavior in children who do not yet understand the word "middle."

Results of the "next to" language condition show that this relatively ambiguous language cue did not lead any children at any of the ages tested to search in the corner of the expanded landmark array as we expected. Indeed, children in the "next to" and "middle" language conditions searched in the middle at the same rate. One possibility is that the "next to" language cue may have increased children's attention to the landmarks. Telling children, "I'm hiding the toy *next to this one*," may have attracted attention to the landmarks, thereby also attracting attention to the relationship between the landmarks and the goal. In Experiment 2, we eliminated the "next to" condition and focused on search behavior in the middle and control conditions with young children.

6.2.4. Spatial Language Comprehension. Parent reports reflected that children's knowledge of the term "middle" increased with age, with parents reporting that 40% of two-year olds, 89% of three-year olds and 100% of four-to six-year olds understood and produced the word "middle." These reports were consistent with previous reports showing that 84% of three-year olds and 100% of four-year olds respond correctly in a "middle" comprehension test [43]. Parents in the current study reported that 89% of three-year olds and 100% of four-year olds comprehended and produced the term "middle," suggesting that our comprehension measure was valid.

Children's searches were consistent with the idea that spatial search was related to comprehension of spatial relational terms. Most children who were reported to know the word "middle" also searched in the middle of the landmark array. Of the children who were reported to understand and produce middle ($n = 31$), 67% searched in the middle and 33% did not. Of the children reported not to understand and produce the word "middle" ($n = 5$), 40% searched in the middle and 60% did not. Because only a small number of parents reported that their children did not comprehend the word "middle," there were too few children to determine whether this difference was statistically significant. Comprehending the term "middle" did not guarantee a middle search strategy. For example, although all children were reported to comprehend the term "middle" by the time they were four years old, 14% of four-year olds searched in locations other than the middle of the expanded array.

7. Experiment 2

In Experiment 2, we focused on the performance of two-, three-, and four-year old children in the middle search task for two reasons. First, the results of Experiment 1 showed that children begin to comprehend the term "middle" between two to four years of age. According to parent reports, comprehension grew from 40% of children at age two to 100% of children at age four. Experiment 2 examined how children's search behavior developed with their understanding of the spatial term "middle" during these years. Second, in Experiment 1, spatial language cues heard during the task seemed to have influenced younger children's performance, whereas older children tended to search in the middle of the expanded array regardless of the language they heard. Therefore, Experiment 2 examined searches of two-, three-, and four-year old children and compared their performance to their score on a middle comprehension test.

7.1. Method

7.1.1. Participants. Seventy-two children completed the experiment, including 24 two-year olds (mean age = 29.96 months, SD = 2.51, range: 25.03–33.4 months) 24 three-year olds (mean age = 42.32 months, SD = 2.87, range: 37.9–47.8 months), and 24 four-year olds (mean age = 53.25 months, SD = 3.48, range: 48.07–59.1 months). All children were from native English-speaking households. An additional 15 children were excluded for failure to meet test criterion (mean age = 28 months, SD = 2.9, range: 24.9–33.8 months).

7.1.2. Materials and Apparatus. The materials and apparatus were the same as those used in Experiment 1, with one minor change to the vocabulary questionnaire. Questions regarding children's experiences with the "middle" relation through books, games, etc. were eliminated from the questionnaire, because parents found the questions hard to answer and often left them incomplete.

7.1.3. Design. There were two between-subjects language conditions: (1) control and (2) "middle." Twelve two-year olds, 12 three-year olds, and 12 four-year olds participated in each language condition.

7.1.4. Procedure. There were two minor changes to the procedure used in Experiment 1. First, all children heard only one language-cued training trial (versus hearing either one or three language-cued training trials in Experiment 1). Second, children completed a forced-choice "middle" comprehension test. Six pairs of cards were used in the test (Figure 5 shows an example of the stimuli). Within each pair, one card pictured the middle relation and one card pictured a different spatial relation (e.g., "bottom," "left"). Three of the six pairs of cards pictured an array of three objects and three of the six pairs pictured an array of five objects. Children were shown two cards at a time and asked to identify the card that pictured the middle relation. For example, children saw a pair of cards, one with a cow in the middle of two horses and another with a cow below two horses. The child was asked, "Can you hand me the card with the cow in the middle?" No feedback was provided. The order of pairs and the location of the correct

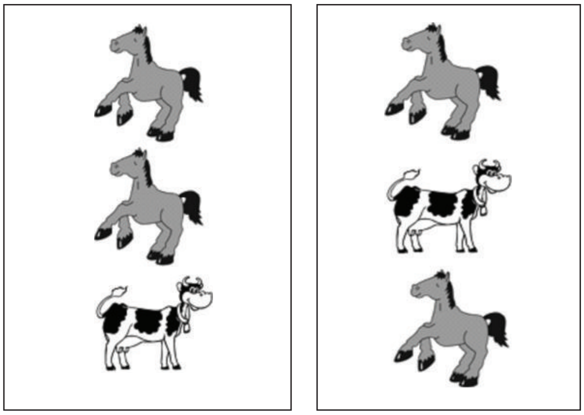


Figure 5: Example of the type of cards used for the comprehension test in Experiment 2.

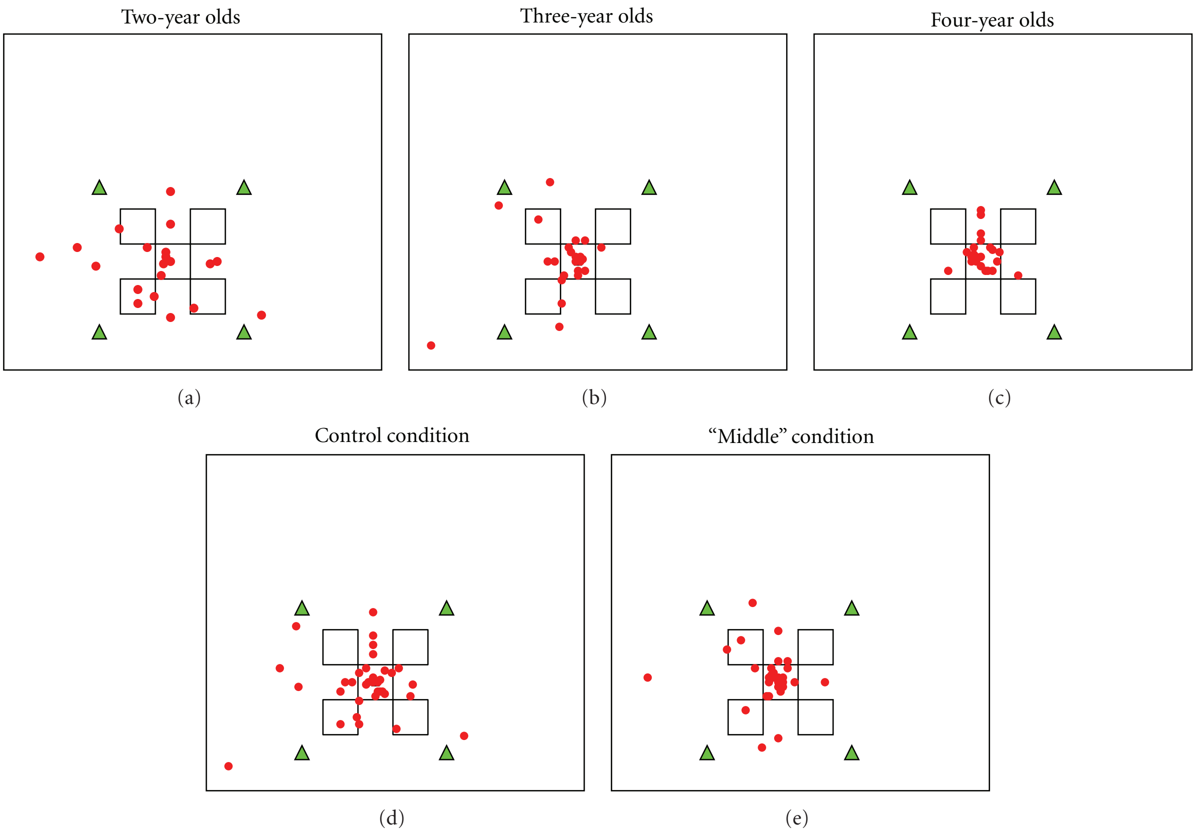


Figure 6: Experiment 2—children's search locations by age and language condition.

card were randomized. The comprehension test was always administered after the search task.

Children's search locations were captured via overhead camera footage. Two independent coders judged the videotapes for children's initial search locations, with 91% agreement between coders regarding the regions of children's searches (middle, corner, other). If children's search locations were not discernible from video footage or if footage was not available ($n = 7$), an average of the charted locations captured from the two experimenters was used to determine the child's search location. If there was disagreement between the two experimenters regarding the search location (middle, corner, other) of a child who was not videotaped, the child would be excluded from the study ($n = 0$).

7.2. Results and Discussion

7.2.1. Training Trials. On average, children required 5.11 uncued training trials to meet criterion (SD = 3.35). There was a significant effect of age on the number of uncued training trials that children required to reach criterion, $F(2, 69) = 15.21$, $P = .00$, $\eta^2 = .31$. Post hoc tests (Tukey's

HSD) revealed that two-year olds (M = 7.71, SD = 4.32) required significantly more search trials to reach criterion than both three-year olds (M = 4, SD = 2.13, P < .01), and four-year olds (M = 3.63, SD = .97, P < .01). There was no effect of gender on the number of uncued training trials children required ($F(3, 64)$ = .35, P = .79, η^2 = .02) and no interaction between age and gender ($F(2, 64)$ = .21, P = .81, η^2 = .01).

7.2.2. Expanded Test Trial. Figure 6 depicts children's initial search locations according to age and language condition. Most children used a middle-search strategy rather than a corner or other search strategy in Experiment 2, $\chi^2(2, n = 72)$ = 12.25, P = .00. Across all ages and both of the language-cued conditions, 51% of children searched in the middle region of the landmark array, and 15% searched in a corner of the array. The remaining 34% of children searched in locations outside of the five designated targets. Of these children, only four searched outside of the expanded landmark array. Analysis of the distance of children's searches from the center of the landmark array revealed that across ages and language conditions, children searched an average of 10.69 cm (SD = 10.39) from the center of the landmark array.

A chi-square revealed that children's search behavior was significantly related to children's age ($\chi^2(2, n = 72)$ = 16.79, P = .00), such that children's tendency to search in the middle region of the landmark array increased with age (Table 2). The distance that children searched from the center of the landmark array was also significantly correlated with age in months (r = −.45, P = .00) and age in years (r = −.49, P = .00). There was no effect of gender on the regions of children's searches. A two-way ANOVA analyzing the distance of children's searches by age and gender showed significant effects. There was a Main effect of age ($F(2, 66)$ = 7.95, P = .00, η^2 = .19), such that two-year olds (M = 16.61, SE = 1.95) searched significantly farther from the center than three-year olds (M = 9.59, SE = 2.04; P = .03), and four-year olds (M = 5.79, SE = 1.95; P = .00). Search distance did not significantly differ between three-year olds and four-year olds (P = .13). Children's searches were also related to gender, such that on average girls (M = 8.13, SE = 1.62) searched closer to the center of the landmark arrays than did boys (M = 13.20, SE = 1.61), $F(1, 66)$ = 4.95, P = .03, η^2 = .07. This was in contrast to the findings of Spetch and Parent [14] showing an advantage for boys in a similar search task. Future research should further investigate the role of gender in children's search strategies. There was no interaction between age and gender, $F(2, 66)$ = .80, P = .45, η^2 = .02.

7.2.3. Spatial Language Cues. As Figure 7 shows, children tended to search in the middle more often if they heard the "middle" search cue. Thirty-nine percent of the children in the control condition compared to 61% of the children in the "middle" condition searched in the middle. A chi-square measuring the number of children who searched in the middle of the expanded array versus the number of children who did not search in the middle by condition found the difference to be marginally significant, $\chi^2(2, n = 72)$ = 2.72, P = .09. The distance that children searched from the center of the landmark array did not significantly differ according to whether children heard "middle" (M = 8.94, SD = 8.63) or control (M = 12.44, SD = 11.77) language cues, $F(1, 70)$ = 2.07, P = .15, η^2 = .03.

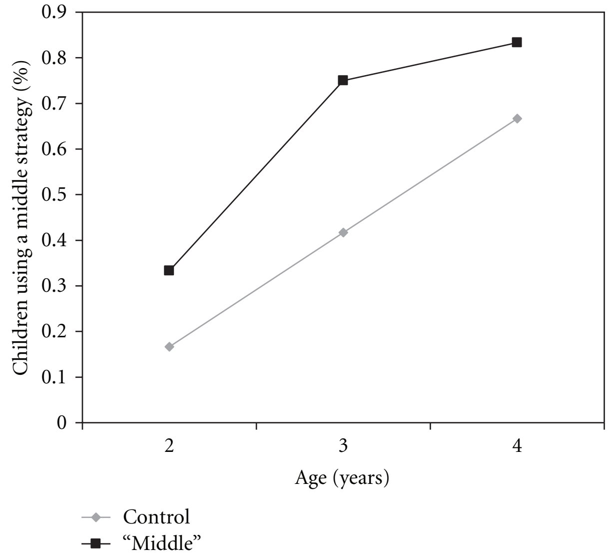


Figure 7: Experiment 2—children's search locations by age and language condition.

7.2.4. Spatial Language Comprehension. Most of the children in this study (68%) were reported to comprehend and produce the term "middle." However, parent reports reflected that children's knowledge of the term "middle" increased with age, $\chi^2(2, n = 72)$ = 24.6, P = .00. According to parent reports, 38% of two-year olds, 88% of three-year olds, and 96% of four-year olds understood or produced the term. Children reported by parents to understand the term "middle" scored an average of 5.17 correct (SD = 1.23) on the middle comprehension test, whereas children reported not to understand the term averaged 2.42 correct (SD = 1.5). An ANOVA revealed that this difference was statistically significant. Parent reports of children's comprehension of the term "middle" were significantly related to children's scores on the forced-choice middle comprehension test, $F(1, 69)$ = 11.78, P = .00, η^2 = .15.

Analysis showed that children's comprehension of the term "middle" was related to children's search behavior. Children's scores on the forced-choice middle comprehension test were significantly related to children's tendency to use middle search behavior, $F(1, 69)$ = 4.25, P = .04, η^2 = .06. Children who searched in the middle had an average score of 4.95 (SD = 1.68) on the comprehension test, whereas children who did not search in the middle had an average score of 3.85 (SD = 1.75). Comprehension test scores were also negatively correlated with children's search distance (r = −.27, P = .02), such that children who scored higher on

Table 1: Experiment 1—children's "Middle" comprehension and search location by age.

Child's age (in years)	Parent reported "Middle" comprehension	Searched in middle	Searched in corner	Searched in other location
2	40%	40%	20%	40%
3	89%	56%	0%	44%
4	100%	86%	0%	14%
5	100%	56%	11%	33%
6	100%	100%	0%	0%

Table 2: Experiment 2—children's "Middle" comprehension and search location by age.

Child's age (years)	Parent reported "Middle" comprehension	"Middle" comprehension test score	Searched in middle	Searched in corner	Searched in other location
2	38%	47%	25%	29%	46%
3	88%	81%	54%	13%	33%
4	96%	95%	79%	4%	17%

the comprehension test tended to search closer to the center of the landmark array. Comprehension test scores were also related to age, $F(2, 69) = 30.69$, $P = .00$, $\eta^2 = .47$, such that children scored higher as a function of age. Post hoc tests (Tukey's HSD) revealed that scores of two-year olds (M = 2.79, SD = 1.5) were significantly lower than those of both three-year olds (M = 4.88, SD = 1.57, $P < .01$), and four-year olds (M = 5.7, SD = .63, $P < .01$). Scores of three- and four-year old children were only marginally statistically different from one another ($P = .09$). Because we tested children on their ability to identify the middle relation in arrays of both three and five objects, we analyzed whether the number of objects pictured influenced children's performance. A paired-samples t-test revealed that there was no difference in children's ability to identify the middle relation in arrays of three (M = 2.24, SD = .96) versus five objects (M = 2.2, SD = 1), $t = .43$.

Parent reports of children's comprehension were significantly related to children's search distance from the center of the array ($F(1, 70) = 6.40$, $P = .01$, $\eta^2 = .08$), but not significantly related to children's tendency to search in the middle region of the landmark array, ($\chi^2(2, n = 72) = 2.63$, $P = .10$). Children searched significantly closer to the middle when parents indicated knowledge of "middle."

Finally, two children in Experiment 2 spontaneously uttered the word "middle" during the course of the task. Both of those children met criteria for using a middle-search strategy.

8. General Discussion

Across two studies, we demonstrated that comprehension of spatial language and spatial language cues provided during the course of a spatial search task were related to children's ability to detect and use spatial relations. Our results revealed that spatial language cues for the middle relation may be particularly helpful to children between the ages of two and four years old, during the same years in which we found children's knowledge of the word "middle" to undergo the most growth. Children's ability to use the middle relation was also related to their comprehension of the associated spatial relational term "middle." Our findings contribute to current literature by showing that spatial language influences children's ability to use landmarks relationally when alternative ways of solving a search task are possible.

It could be argued that our participants searched in the middle of the landmark array simply because children are biased to search in the middle of a continuous space or because the middle location represents the central tendency [44]. If children's attention was drawn toward the center because of some natural tendency unrelated to comprehension of the middle relation, however, then all children would have searched in the center regardless of their comprehension of the term "middle" or the type of language they heard during the course of the study. This was not the case; we found that children's tendency to search in the center of the landmark array was significantly related to children's spatial language comprehension and marginally related to spatial language cues. Thus, it appears that children's middle searches were not random.

Nonhuman species, including pigeons [20], gerbils [18], and marmoset monkeys [16], consistently use the distance and direction from a single landmark to solve this task (i.e., corner search). Research shows that children begin to use single landmarks before they use multiple landmarks relationally [2, 15]. This trajectory of landmark use is in line with Gentner's [11] description of the "relational shift" wherein children initially rely on simple strategies before they develop the ability to act on complex relational information. We did not, however, observe this course of development in the current task—that is, there was no tendency for younger children to use a single landmark. Instead, children who did not search in the middle of the landmark array tended to search at some other location inside the imaginary boundary created by the array of landmarks. In fact, children only rarely used a corner strategy in this task, suggesting that young children did not favor using a single landmark over using multiple landmarks despite the fact that both methods of solving the task were possible. We suggest two possible explanations for why we did not observe a relational shift in children's landmark use. First, children's searches may have been imprecise. According to the stringent criteria used in this task, children's initial hand placement in the sand must have been within a fairly small region to count as a middle or corner search. Second, the majority of children in the current studies were reported by parents to understand the word "middle," including 40% of two-year olds. To further examine whether children initially prefer a single landmark strategy, future research should investigate children's multiple landmark use prior to two years old.

8.1. Spatial Language Comprehension. Research in other domains has revealed a temporal link between children's emerging skills and related vocabulary growth [26, 27, 33]. The current studies also reveal a temporal link between children's ability to use the middle spatial relation and the development of related spatial language. That is, children's search behavior was related to children's comprehension of the spatial term "middle." Searching in the middle of the landmark array was significantly related to children's performance on a forced-choice middle comprehension task. Previous research has described an anecdotal relationship between children's comprehension of the term "middle" and children's search behavior [13, 16]. For example, MacDonald et al. [16] reported that the two children who searched closest to the center of the expanded landmark array also spontaneously uttered the term "middle" during the task. We observed similar behavior in Experiment 2, as two children who met criteria for searching in the middle of the landmark array also spontaneously said "middle." This combined with the clear link between comprehension and searching in the current studies suggests that language was affecting children's search behavior.

Although there was a relationship between children's spatial language comprehension and children's search behavior, we cannot determine the direction of the relationship from the current study. There are competing views regarding the direction of the relationship between spatial language and spatial cognition [26, 33, 45–48]. At the extreme ends of this debate, theorists argue that: (1) language is necessary for spatial category formation and language guides children's attention to relevant spatial information [26, 33], or (2) spatial information is already nonlinguistically available to children, and language simply helps to select which of many ways of carving up space the child uses as a language convention [48]. Support for the latter viewpoint is that several habituation studies have shown that even preverbal infants can be trained to identify and categorize spatial relationships [49, 50], including those not used in their native language [51, 52]. However, this is not true for all spatial categories, such as the support "on" relation [53, 54]. In cases in which spatial relations are less easily abstracted, hearing a spatial word can facilitate category acquisition. For example, when trained with the word "on", infants were successful in learning the support relation, but without the "on" label children did not learn [53], suggesting that spatial terms may be essential for forming some spatial categories. As a whole, evidence for the direction of language and thought is mixed. One possibility is that spatial language and spatial concepts develop simultaneously and are initially contextually bound such that the precise nature of the task influences the roles of language and cognition. Future research should investigate the direction of the relationship between children's "middle" comprehension and children's landmark use.

Although there was a relationship between "middle" comprehension and searching, comprehending the term "middle" did not guarantee middle search behavior. Instead, across all ages, searching in the middle appeared to lag behind comprehension of the term "middle" (see Tables 1 and 2). We offer two possible reasons. First, children may exhibit comprehension of the term "middle" in some contexts, but not others. Dissociation between comprehension of a spatial term and the ability to use the associated concept in a search task has also been found in regard to the "left/right" relation. Well after the terms "left" and "right" enter children's productive vocabularies, children continue to experience left/right confusion [55–57]. Children may exhibit similar difficulty with the word "middle," causing an inability to accurately apply the term to a spatial task even after the term has entered a child's vocabulary. Second, children may comprehend the term "middle," but fail to see its relationship to the current spatial task. Support for this claim can be found in our finding that cueing children with the term "middle" was marginally significantly related to children's ability to use the spatial relationship in this task. Experimenter-provided spatial relational language cues appeared particularly effective for younger children, ages two to four years old, the ages at which children are gaining proficiency with the word "middle." This suggests that when children are first acquiring spatial language, they may especially benefit from being prompted with associated language when performing a spatial task. This finding also adds to a growing body of research on children's categorization (see [11] for a review), showing that relational reasoning is difficult for young children but may be aided by linguistic cues.

8.2. Spatial Language Cues. Our findings regarding experimenter-provided spatial language cues provide a possible explanation for why previous studies have shown differing results regarding children's ability to use multiple landmarks [2, 13–16]. Whereas some studies show that children can use the middle relation to find a hidden object by four or five years of age [2, 15], other studies show that children at these ages do not always use a middle search strategy when other methods of solving the task are possible [16]. Situational factors, such as experimenter-provided language input, may influence children's relational reasoning. Thus, one possibility is that the multiple differences between past investigations of the middle relation (e.g., some studies used two landmarks while others used four landmarks, some studies used an open field while other studies used a small box, etc.) differentially support children's relational reasoning.

The question of how spatial language cues may have facilitated children's relational abstraction remains unanswered. It is possible that cueing children with the term "middle" may have activated children's knowledge of the spatial term "middle." In that case, the term "middle" would prove uniquely helpful to children's performance compared to any other type of language cue. Some support for this idea can be seen in Loewenstein and Gentner's [11] study of children's ability to use the middle relation to retrieve an object on the middle shelf of a set of three shelves. Their results showed that specific spatial relational terms (i.e., top, middle, bottom) were more helpful than less specific terms (i.e., in, on, under). On the other hand, the spatial relational cue provided to children in the current study may have been helpful simply because it heightened children's attention to the relationship between the landmarks and the goal. Some evidence for this account can be found in the results of Experiment 1. We found that rather than causing children to search in the corner of the landmark array, the "next to" language cue ("I'm hiding the toy *next to this one*,") may have actually led more children to search in the middle of the landmark array. This suggests that any cue that heightens children's attention to the landmark array may also heighten children's attention to the relationship between the goal and multiple landmarks, thereby facilitating middle search behavior. In that case, heightening attention in other ways, including providing a different label ("I'm hiding the toy *in the blicket*") or manipulating landmarks themselves such that their relationship to one another is highlighted (e.g., four arrows pointing toward the center) may serve the same facilitative purpose. Future research should examine these possibilities to determine *how* middle language cues influence children's ability to act on the middle relation.

9. Conclusions

In the current studies, children's comprehension of spatial language and spatial language cues provided during the search task influenced children's use of landmarks. Children's comprehension of the word "middle" was significantly related to children's ability to perform middle searches among multiple landmarks. We also found that simply hearing the spatial term "middle" once was marginally related to increased middle searches, revealing language as one way to facilitate children's ability to notice and act on spatial relations. Because even some two-year olds in this study demonstrated comprehension of the term "middle," further research should be conducted to investigate how children search among multiple landmarks prior to the acquisition of related spatial language. Although we cannot determine the direction of the relationship between children's "middle" comprehension and increased middle searches from the current studies, these findings demonstrate the strong relationship between children's spatial vocabulary development and the ability to use multiple landmarks in conjunction. With the acquisition of spatial language children become more skilled landmark users, emphasizing the central role of language in children's developing ability to reason about relations.

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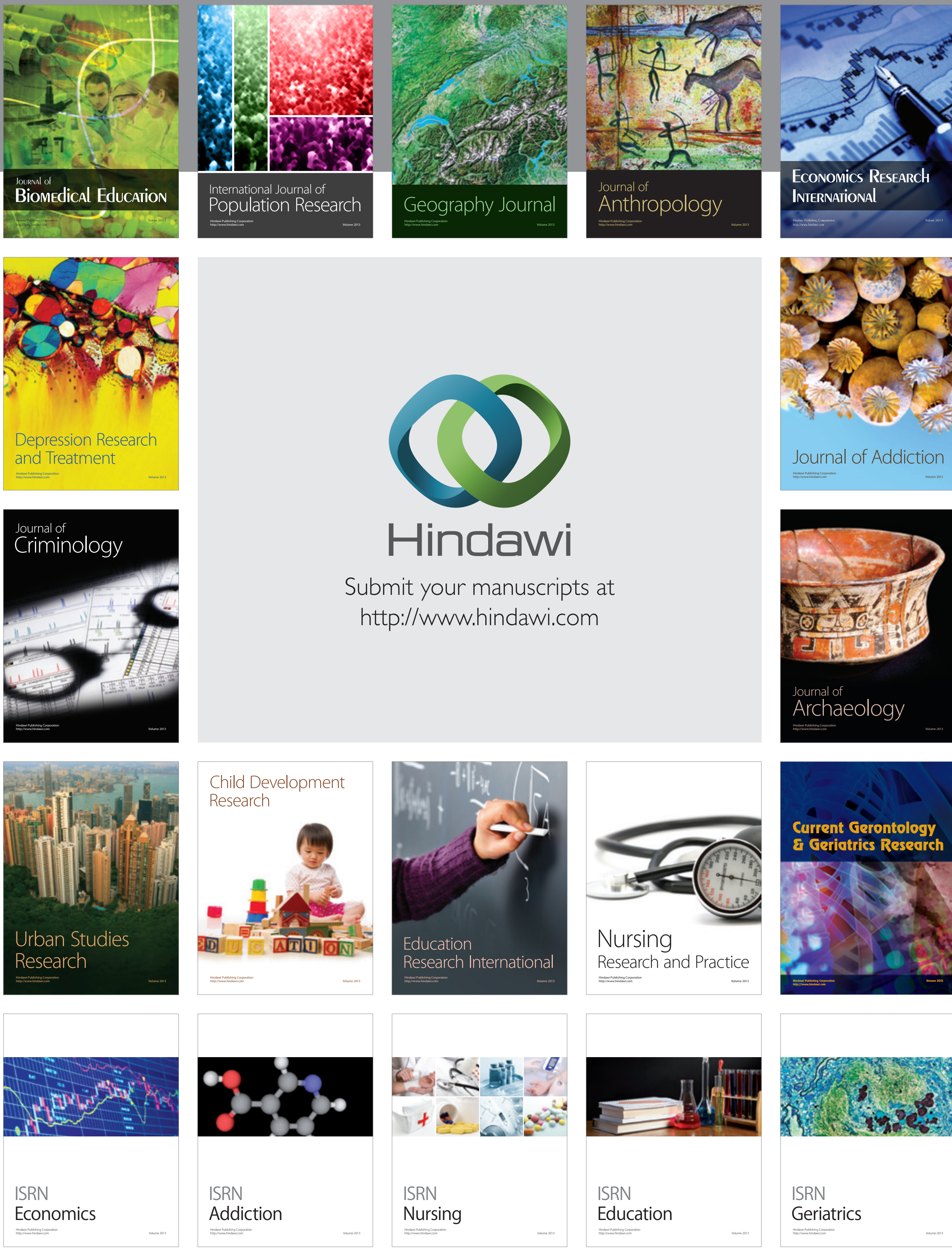
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