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Spatial Language and Landmark Use: Can 3-, 4-, and 5-year-olds find the *Middle*?

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Abstract

Evidence suggests that (a) young children have difficulty reasoning about spatial relations, and that (b) spatial language can facilitate their performance (Loewenstein & Gentner, 2005). This study investigates children's ability to reason about a particular spatial relation, *middle*, which we hypothesize may be particularly challenging. We ask when children become able to encode the *middle* and whether this ability is related to acquisition of the words "middle" and "between." Finally, we explored the errors children make when reasoning about *middle*. We gave 3-, 4-, and 5-year-old children a search task in which the hidden object was always in the middle of two landmarks (Midpoint Task), followed by a language task assessing their understanding of the spatial relational terms "middle" and "between." Children's accuracy on the Midpoint search task increased with age; and, more interestingly, increased with knowledge of the relevant words.

Keywords: Relational reasoning; language; spatial relations; cognitive development.

Introduction

The ability to recognize and reason about relations is critical to the human capacity for higher order cognition. In fact, it is so powerful and so fundamental that it has been offered as a major part of the reason why "we're so smart" (Gentner, 2003). Despite adults' fluency with relational concepts, young children have repeatedly demonstrated difficulty with tasks that require them to focus on relations, especially in those instances where they must ignore or abstract across the identity or perceptual properties of the entities involved in the relations. For example, Christie and Gentner (2007) gave 4½- and 8½-year-olds a simple relational task that has been used in comparative studies (e.g., Thompson, Oden & Boysen, 1997). Children were shown a standard with two identical objects (e.g. two squares) and were asked to match it to one of two choices: a relational match, which had two identical new objects (e.g. two triangles) or an object match, which had two different objects, one of which was identical to the standard's objects (e.g. a circle and a square). The 4½-year-olds significantly preferred the object match over the relational match, and even the 8½-year-olds failed to show a reliable preference for the relational match. Richland, Morrison, and Holyoak (2006) demonstrated a similar phenomenon using line drawings of event scenes. In their study they showed children two scenes, and then asked them to find an object

in the second scene that played the same role as some object in the first scene. Importantly, when the object from the first scene was also in the second scene but played a different role, young children were likely to pick the identical object rather than the object in the same role in the event.

The shift from a focus on perceptual properties and from objects to relations has been termed the *relational shift* (Gentner, 1988). Many factors have been proposed to contribute to such a shift, including maturational changes in cognitive capacity (Halford, 1993), increases in domain knowledge (Gentner & Rattermann, 1991), and the representational affordances of language (Gentner, 2003). Strikingly, children display difficulty reasoning about relations even in domains, like space, that are accessible to them and in which they are likely to have fairly extensive experience. Loewenstein and Gentner (2005) found that 3-year-olds had trouble mapping the location of an object from one three-tiered box to another, identical box. In another spatial mapping task, 3-year-olds failed to use the spatial relations in a model room to distinguish between two identical objects in the room. They were successful at locating a hidden object only when it was placed at a unique object, but chose randomly between two identical objects in different relative locations (Blades & Cooke, 1994), although having an opportunity to compare two similar models improved their performance dramatically (Loewenstein & Gentner, 2001).

However, even very young children are able to use spatial relational information in certain kinds of navigation and search tasks (Bushnell et al., 1995; Newcombe et al., 1998). In particular, children can encode location relative to landmarks. There are three main types of landmark encoding strategies: *beacon*, *vector*, and *relational* (Figure 1). *Beacon* coding refers to the use of a single landmark as a general marker for location. This kind of encoding roughly corresponds to spatial relations such as *at*, *by*, or *near*. In Figure 1, X would be encoded as lying somewhere proximal to the landmark (e.g. somewhere inside the circle). *Vector* coding, in contrast, specifies a direction and distance (or vector) from a particular landmark. In this case, distal locations could be encoded relative to the landmark. In Figure 1, this is represented by the arrow from the landmark to X. Finally, *relational* coding marks location relative to multiple landmarks in an array, rather than to a single

landmark. The arrows from both landmarks in Figure 1 represent this strategy.

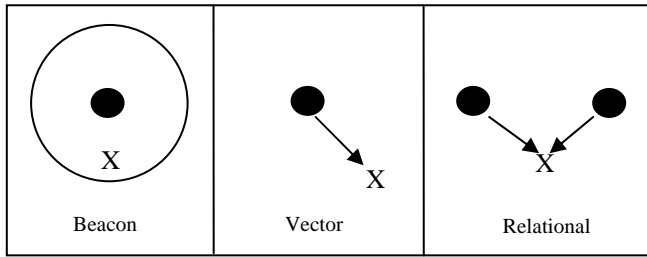


Figure 1: Location encoding strategies.

Children as young as one year old can locate objects using a beacon strategy, which only requires direct coding of the location of a single landmark. For example, if a toy is hidden in an array of small pillows, 1-year-olds can find the toy if it is directly under a distinctive pillow (Bushnell et al., 1995). But they are unable to encode a position relative to a landmark (i.e., to use a vector strategy): they do not search under the correct pillow when the toy is hidden under a contiguous, non-distinctive pillow. However, by the end of the second year, children are able to encode location in terms of its vector (its distance and direction) from a single landmark (Bushnell et al., 1995; Newcombe et al., 1998).

In this research, we ask when children become able to coordinate more than one landmark in location encoding: specifically, how do children encode the spatial relation of *middle*. *Middle*, along with its counterpart *between*, involves an object's relationship to two or more ground objects simultaneously (e.g. "The boy sat *in the middle of/between* his mom and dad."). It has been argued that infants as young as 6 months old can form a categorical representation of *between* (Quinn et al., 2003; Quinn et al., 1999), but using an encoding strategy to find an object hidden in the middle of a configuration requires quite a different set of capabilities.

MacDonald et al. (2004) trained 5- to 9-year-old children to find a treat in the middle of four landmarks forming a square, placed on a grid-like matrix (the space was not continuous). Once children could reliably find the treat, the landmarks were expanded to a new distance while preserving the relative configuration (square). Unlike adults, who searched in the center of the square after expansion, the children searched close to individual landmarks, suggesting that they had encoded the location using a single-landmark strategy such as a beacon or vector strategy, rather than a relational one. Younger children, aged 3- to 5-years, also failed to search in the middle of four expanded landmarks when trained and tested in a continuous search space (MacDonald et al., 2004).

However, success in a four-landmark array may be an unnecessarily stringent test of children's ability to make use

of multiple landmarks (Uttal, Sandstrom, & Newcombe, 2006). Locating an object in the middle of two landmarks still requires that children encode location with respect to a configuration, but there are fewer spatial relations that must be considered simultaneously. Studies that have used two-landmark arrays have produced conflicting results. Uttal et al. took children to a large open field and showed them that a toy would be hidden in the middle of two chairs. After the children demonstrated that they could locate the hidden toy with the same inter-landmark distance as at training (6 meters), the chairs were surreptitiously moved further apart. All of the 4- and 5-year-olds correctly searched for the toy in the middle of the expanded landmarks. In contrast, Spetch and Parent (2006) found that only 14 out of 38 3-, 4-, and 5-year-olds were able to reliably locate a hidden object in the middle of two landmarks in small-scale, discrete space (a row of small boxes), even before expanding the landmarks. This study also found that by 5-years-old, boys were significantly better at the task than girls, a gender effect that has not been reported in other studies investigating the development of relational landmark use in children. A male advantage is well established in many spatial cognitive tasks but is not usually present until children are older (Linn & Petersen, 1985; Jones et al., 2003).

One intriguing finding to emerge from the work on the development of a *middle* strategy in children comes from MacDonald et al. (2004). In their task with 3- to 5-year-olds, there were a few children who did concentrate their search for the goal in the middle of the four landmarks, rather than at the training vector from one landmark, and these children were the same ones who also spontaneously used the word "middle" during the task. Interestingly, these few children were not simply the oldest – one of them was only about 3½ years old.

This result is in accord with findings suggesting that children's ability to reason about space is bolstered by their relevant linguistic knowledge. For instance, Hermer-Vazquez, Moffet, and Munkholm (2001) had preschool children try to remember in which corner of a rectangular room with a single distinguishable wall an object was hidden and found that their ability to do so was correlated with their knowledge of relevant spatial terms, specifically "left" and "right." Likewise, Loewenstein and Gentner (2005) found that preschool children were much more successful at a spatial mapping task when labels were provided for them. They showed preschoolers where a star was hidden in one three-level box and told the children that they would find another star in the same place in a corresponding box. Children who were given the labels "on," "in," and "under" or "top," "middle," and "bottom" for the different levels of the box were far more accurate in their searches than children who were asked to perform the task without any linguistic reminders.

The present study addresses several questions raised by the above discussion: (1) when does the ability to encode location relative to two landmarks emerge, specifically the ability to encode *in the middle*, (2) what is the relationship between this ability and knowledge of the words “middle” and “between,” and (3) what errors do children make when reasoning about *middle*? To investigate these questions, children participated in a hide-and-seek game in which they had to find a hidden object in the middle of two flags. After this game, children were given a language task to assess their production and comprehension of the words *middle* and *between* (as well as some other simple spatial terms). Finally, the relationship between children’s performance on these two tasks was assessed.

Methods

Participants

Twenty-nine 3-year-olds (30-41 months, $M = 34.93$), 22 4-year-olds (42-53 months, $M = 46.36$), and 23 5-year-olds (54-65 months, $M = 58.30$) recruited from the university’s surrounding areas participated in this study. The data from seven 3-year-olds, three 4-year-olds, and one 5-year-old were excluded due to failure to meet certain criteria, outlined in the Procedure and Results sections, leaving 22 3-year-olds ($M = 35.36$), 19 4-year-olds ($M = 46.79$), and 22 5-year-olds ($M = 58.00$) in the final analysis. All children were run in our laboratory on campus and received a t-shirt and a book or small toy prize for their participation. All were normally-developing, monolingual English speakers.

Materials and Procedure

Children participated in a single session, in a 6’ x 10’ testing room. The Midpoint Task was administered first, followed by the Language Task. For both portions of the session, the children and experimenter faced each other across the finding box.

Midpoint Task A 72” x 8” x 9” box constructed with hardboard and filled with Styrofoam packing peanuts served as the finding box. The hiding object was a 1.5” x 1” x 1” yellow, plastic treasure chest, inside which farm animal stickers were placed. In order to prevent the treasure chest from moving as children searched for it, a strip of Velcro was attached to its bottom, as well as along the inside bottom of the finding box. One red and one blue flag served as landmarks.

Throughout the Midpoint Task, children were required to first point to the location of the hidden treasure chest before digging to retrieve it. There were three phases to the Midpoint Task: the pointing practice, the training, and the test. The pointing practice was implemented to ensure the children could accurately point and allow the experimenter to record their response before attempting to find the

treasure chest. In this phase, the child watched the experimenter bury the treasure chest at different locations in the finding box two to four times (without landmarks) and was encouraged to point to its location before digging. If children failed to point accurately on at least two practice trials, their data were omitted from data analyses.

In the training phase, the experimenter introduced the landmarks. The child watched as the experimenter placed the flags twelve inches apart in the finding box and buried the treasure chest in the center of the two flags. The blue flag was always placed on the child’s left, and the red flag on his or her right. This was repeated at another location in the finding box, for a total of two training trials. The experimenter did not use the words “middle” or “between” during training. Children who were unable to point accurately on both training trials were excluded from further analyses.

Finally, in the test phase, children were asked to turn around and close their eyes while the experimenter hid the treasure chest. As a precaution against children accidentally seeing where the treasure chest was being hidden or being able to locate it by audible cues, the experimenter was careful to always put both hands under the Styrofoam peanuts, in separate locations, while hiding the treasure chest. As in the pointing and training phases, children were asked to point to the location of the treasure chest before digging.

A maximum of nine test trials were administered to each child, in different locations and with varying inter-landmark distances. Not all children completed every trial. Throughout the nine test trials, the distance between the two flags was increased and decreased, in the following pattern: 12”, 12”, 24”, 12”, 36”, 12”, 24”, 12”, 36”. On the final four test trials, the red and blue flags were switched so that the red flag was on the child’s left and the blue on his or her right. Children were allowed to search until they found the treasure chest, but only the location of the child’s first point was used in data analyses.

At the end of the Midpoint Task, children were asked, “How did you know where to look for the treasure chest?” Their answers were recorded. Additionally, any spontaneous productions of either “middle” or “between” were noted throughout the task.

Language Task The Language Task immediately followed the Midpoint Task. It was composed of three parts: production, comprehension, and forced-choice comprehension. These were administered in that order for all children. A small plastic cow and pig served as reference objects throughout the language task. Ground objects were two of each of the following small, unpainted wooden figurines: car, airplane, basket, crib, cabinet, and table. Before beginning the language task, children’s knowledge of the object labels was assessed, to ensure that any error or confusion was not caused by labels for the individual items

rather than unfamiliarity with the spatial prepositions themselves.

The spatial prepositions *middle* and *between*, along with several other prepositions, were tested in all sections of the language task. These additional prepositions served to calibrate children’s general language knowledge, as well as to disguise the main intent of the task.

On production trials, children were shown arrays with two objects and a small plastic cow and asked, “Where’s the cow?” On comprehension trials, children were also shown arrays with two objects, but were told to put a small plastic pig in the appropriate relation (e.g. “Put the pig between the airplanes.”). Finally, on forced-choice comprehension trials, children were shown two identical two-object arrays, one with the pig in one relation (e.g. on the basket) and the other with the cow in a different relation (e.g. in the basket). The children were then asked, for example, “Is the pig or the cow in the basket?”

Results

Coding and Exclusion Criteria

During the task, the location of each child’s points were marked on a length of ribbon and measured to the nearest half inch. Each location was then coded as a correct or incorrect response. On trials with flags spaced 12 in. apart, responses within one-and-a-half inches on either side of the correct location were coded as correct. This margin was increased a half inch for every 12 inches the flags were expanded, so that responses to 24 in. trials were given two inches on either side and responses to 36 in. trials were given two-and-a-half inches on either side. A one-and-a-half inch margin was used for the pointing and training trials as well. Children who were unable to point within this margin on at least two pointing trials and both training trials, their data were excluded from further analysis.

Incorrect responses were further coded into several error types: *beacon*, *vector*, *perseverative*, and *other*. *Beacon* errors reflected the children’s use of a beacon encoding strategy, resulting in search near the flags themselves. *Vector* errors retained the same distance and direction from a flag as at training (i.e. six inches from one of the flags). *Perseverative* errors refer to instances in which children searched for the treasure chest at the same location it was found on the previous trial. Finally, *other* errors consist of any responses made that did not fall into one of the previously described categories. In addition, errors were coded more generally as *within* or *outside* the flags, in order to ascertain the degree to which children understood that the treasure chest was to be found between the flags, even if they did not understand that it should be precisely in the middle.

Midpoint Task Accuracy

Not all children completed every trial. Because some children did not complete the entire task, children’s performance was measured by proportion correct out of the total number administered. To investigate the effects of age and gender on performance, these scores were entered into a 2(gender) x 3(age) univariate ANOVA. The effect of age was significant, $F(2,56)=12.51, p < .001$, and post-hoc tests revealed that the 3-year-olds ($M = 0.34, SD = 0.25$) were significantly less accurate than either the 4- or 5-year-olds ($M = 0.68, SD = 0.25; M = 0.72, SD = 0.30$), Bonferroni, $p < .001$. The 4- and 5-year-olds’ performances did not differ significantly from one another. Neither an effect of gender nor a gender by age interaction was significant.

As previous studies have done, we also analyzed performance on the first expanded trial. The proportion of 3-year-olds ($M = 0.19$) who answered correctly was significantly lower than the proportion of 5-year-olds ($M = 0.73$) who did so, Bonferroni, $p < .05$. The proportion of 4-year-olds ($M = 0.50$) who answered correctly did not differ significantly from either the 3-year-olds or the 5-year-olds. Again, no gender effects were found.

Word Knowledge and Accuracy

As in McDonald et al.’s (2004) study, children who produced the words *middle* or *between* during the Midpoint Task, either spontaneously or in response to the question, “How did you know where to look for the treasure chest?” were more accurate than children who did not (Table 1).

Table 1: Mean proportion correct for producers and non-producers of *middle* or *between* during the Midpoint Task

	3-year-olds	4-year-olds	5-year-olds	Total
Producers	0.56 N = 1	0.79 N = 4	0.83 N = 3	0.78 N = 8
Non-producers	0.29 N = 21	0.64 N=15	0.68 N=19	0.52 N = 55

To further investigate the relationship between word knowledge and accuracy, age in months and proportion correct on *middle/between* trials from the Language Task were entered into a standard regression, along with their interaction term. The model accounted for 40% of the variance and was significant, $F(3,55)=12.14, p < .001$. Both age, $\beta = 0.02, p < .01$, and proportion correct on *middle/between* trials, $\beta = 0.27, p < .05$, were significant predictors of performance on the midpoint task, though the interaction between these two factors was not.

Table 2: Mean proportion of responses on Midpoint Task by type out of total trials completed

	3-year-olds N = 22	4-year-olds N = 18	5-year-olds N = 22	Total N = 62
	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>
Correct	0.34 (0.25)	0.68 (0.25)	0.72 (0.30)	0.58 (0.31)
Beacon	0.04 (0.12)	0.00 (0.00)	0.00 (0.00)	0.02 (0.07)
Vector	0.12 (0.14)	0.09 (0.16)	0.03 (0.08)	0.08 (0.13)
Perseverative	0.05 (0.08)	0.05 (0.07)	0.06 (0.08)	0.05 (0.08)
Other	0.44 (0.27)	0.18 (0.15)	0.18 (0.28)	0.27 (0.27)
Within	0.34 (0.16)	0.27 (0.21)	0.18 (0.15)	0.26 (0.18)
Outside	0.31 (0.27)	0.05 (0.10)	0.10 (0.22)	0.16 (0.24)

Errors

Table 2 shows the mean proportion of each response type (including correct responses) out of the total number of trials for each age group. One striking finding is that 3-year-olds frequently searched outside of the flags – on average nearly a third of their responses fell outside the flags. Their errors did not merely lack metric precision, but rather the 3-year-olds did not understand that the toy was hidden between the flags.

To evaluate whether children’s error patterns changed with age, their mean proportions of each error out of the total number of trials completed were entered into a 3(age) x 4(error) repeated measures ANOVA. The interaction between age and error type was significant, $F(2,59) = 4.07$, $p < .05$, suggesting that children’s errors did not decline uniformly with age. Follow-up univariate ANOVAs performed on each error type indicated that a main effect of age was significant only for *other* errors, $F(2,59) = 8.00$, $p < .01$, although the effect was marginally significant for *beacon* errors, $F(2,59) = 2.51$, $p = .09$, and *vector* errors, $F(2,59) = 2.51$, $p = .09$.

Discussion

This study sought to investigate the following questions: (1) when does the ability to encode location as *in the middle* emerge, (2) what is the relationship between this ability and knowledge of the words “middle” and “between,” and (3) what errors do children make when reasoning about *middle*? By 4-years-old, and definitely by 5-years-old, children are able to encode location relative to two landmarks in a small-scale continuous space. In contrast, 3-year-olds appear to have a great deal of difficulty with this. The results of this study also revealed a relationship between knowledge of the words “middle” and “between” and the ability to encode location as *in the middle*. Children who used those words during the Midpoint Task were more successful at the task than children who did not, a finding also reported by McDonald et al. (2004). Additionally, knowledge of “middle” and “between,” as assessed by the Language Task, predicted performance on the Midpoint Task beyond what

was predicted by age. Finally, the analysis of children’s errors on the Midpoint Task revealed one especially striking result: 3-year-olds, in contrast to 4- and 5-year-olds, searched for the hidden object outside of the flags nearly one third of the time. This suggests that the 3-year-olds were not merely making errors due to lack of metric precision, they were not able to encode location as between the flags. In general, children’s errors on the Midpoint Task decreased uniformly with age, with the exception of *other* errors. Because these errors did not fall into categories predicted in the previous literature, it is difficult to draw many conclusions from this except to say that children’s errors became more systematic with age.

As we did, Uttal et al. (2006) found that 4- and 5-year-olds could encode location as *in the middle*, but unlike in our study, all of their participants were successful on the first expanded trial. In this study most of the 5-year-olds, but only half of the 4-year-olds, accurately pointed to the middle on the first expanded trial. One key difference between this study and Uttal et al. is the scale of the space. Previous research has demonstrated that children may be more successful reasoning spatially in larger, rather than smaller, spaces (Learmonth, Newcombe, & Huttenlocher, 2001). Also in contrast to Uttal et al.’s task, in which the location of the hidden object did not change across trials, the hidden object moved on every trial in this study. Although a control condition in Uttal et al. suggested that children were not able to find the hidden toy by dead-reckoning alone, this may have contributed to their greater success on their task than on ours.

A remaining question from this study is the directionality of the link between word knowledge and success with *middle*. Language has been proposed to facilitate conceptual understanding (Gentner, 2003; Gentner & Namy, 1999; Gentner & Rattermann, 1991; Loewenstein & Gentner, 2005), and it might be that when children have ready access to the word “middle,” they can more easily encode location in those terms. Current work is investigating whether training with the word “middle” helps children appropriately encode location as *in the middle*, to examine this proposal. Future studies will also investigate whether there are different learning trajectories for encoding *between* versus *middle*. Not only did three-year-olds not reliably

search in the middle of two landmarks, they also had trouble encoding location as between these landmarks. Four- and 5-year olds, in contrast, did both.

In conclusion, this study suggests that children's proficiency with *middle* improved with age, and more importantly, with relevant word knowledge. Further work is needed to investigate exactly how language interacts with the ability to encode location as *in the middle* and whether language can be used as a tool to facilitate young children's spatial ability.

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