Distribution Agreement

How Children Use Landmarks in a Geometrical Space

by

Janine Cabrera

Dr. Stella Lourenco
Adviser

Psychology

Dr. Barbara Strock
Committee Member

Dr. Richard Rubinson
Committee Member

2012

How Children Use Landmarks in a Geometrical Space

By

Janine Cabrera

Dr. Stella Lourenco
Adviser

An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences
of Emory University in partial fulfillment
of the requirements of the degree of
Bachelor of Arts with Honors

Psychology

2012

Abstract

How Children Use Landmarks in a Geometrical Space
By Janine Cabrera

The present study borrows from Graham et al. (2006) to address the conflicting theories that exist about the use of both geometry and landmarks in children. Across both 3- and 4-year-olds, there was improvement in performance in using the geometry of a kite-shaped space (no landmark trials) when they were exposed previously to featural cues, specifically, different colored walls in this space (landmark trials). This means that learning about the shape of a fairly complex enclosure was affected by the color of the walls in that shape. Together, these findings question the validity of a geometric module, which must be addressed in future studies.

Keywords: children, geometry, landmark, featural cues, geometric module

How Children Use Landmarks in a Geometrical Space

By

Janine Cabrera

Dr. Stella Lourenco
Adviser

A thesis submitted to the Faculty of Emory College of Arts and Sciences
of Emory University in partial fulfillment
of the requirements of the degree of
Bachelor of Arts with Honors

Psychology

2012

Acknowledgements

I would like to thank my adviser, Dr. Stella Lourenco, and each of my committee members for all of their input in my honors thesis.

Table of Contents

How Children Use Landmarks in a Geometrical Space

Imagine you are blindfolded and placed in the middle of an unfamiliar city. You experience confusion and find yourself disoriented. How do you reorient? As you begin to analyze your surroundings, perhaps you notice salient landmarks such as the Statue of Liberty or the Empire State Building and realize that you are in New York, specifically New York City. Or, perhaps, you approach the situation using another strategy. Instead of specific landmarks, you attend to geometry using distances and angles such as how far you are from both the Brooklyn Bridge and the Hudson River. Based on these different perspectives, new theories have emerged to account for how human organisms reorient in space, that is, what types of information we use and favor to solve this problem.

Geometric Module in Children

Hermer and Spelke (1994) tested navigation, specifically the process of reorientation, in children aged 18-24 months and found evidence of their using geometry. Each child was put into a white rectangular room and a toy was hidden in one of its corners. In this task, there is a disorientation procedure, which occurs after hiding and before retrieval. It involves the child being picked up by the parent and being spun around with his or her eyes closed several times. When children searched, there was an interesting pattern. Children tended to search at two identical corners at equal rates -- namely, the correct corner and its "rotational equivalent." Similar search patterns were also found in other studies (Hermer and Spelke, 1996; Lourenco, 2005). In a rectangular space, these could be the two corners with the long wall to the right and the short wall to the left. According to Cheng (2005), this 180° rotational equivalent is called the rotational error (see Figure 1), which demonstrates that a location has been defined by geometric cues. Because children in this study searched in the correct corner and its geometric equivalent at rates above chance, it shows that they use the geometry of the space (i.e., the rectangular space) to reorient.

The same pattern of search was observed when children were exposed to the same geometric space but were given additional featural information. In this condition, one of the walls was blue. This means there should not be rotational errors since the blue wall disambiguates the corners. In a rectangular space, there could be one long *blue* wall to the right and a short white wall to the left versus a long *white* wall to the right and short white wall to the left. Children demonstrated similar search patterns in this condition, indicating that the landmark (i.e., blue wall) was not readily used or perhaps even completely ignored. The same results were also found when the landmark was a solid object, which was expected to draw children's attention more readily than a different colored wall. The theory that children are predisposed to encode geometric information more readily than other cues brought forth the idea of a "geometric module." This theory has greatly impacted cognitive development because it suggests that there is a structure in the brain, a distinct "module," which has the sole purpose of processing geometry and nothing else. Furthermore cognitive psychologist, Randy Gallistel (1990), has suggested that processing geometry to help define a location may be essential for survival. He believes geometry is more useful than single landmarks because geometry is more stable.

There have also been a series of studies that show that children's ability to use geometric cues is generalizable to spaces of different shapes and the viewer's relation to the space, which demonstrates that geometry is used under different conditions. Huttenlocher and Vasilyeva (2003) found that both 3- and 4-year-olds could locate an object after disorientation both inside and outside triangular (isosceles) and rectangular spaces using geometry. In these experiments, spaces were large enough that children could move around comfortably from inside, but small enough that they could see the entire space when standing outside them. The ability to determine where the toy was hidden, both exteriorly and interiorly, shows that children are able to encode the properties of an entire space rather than have it be defined by their own relation to it. Although children searched in the geometrically appropriate corners at higher rates when inside, compared to outside, the space (both for triangular and rectangular shapes), their performance from outside was still above chance. Other studies have included more complex geometric shapes, such as an octagonal space, observing similar results in children as young as 2 years of age (Newcombe, Ratcliff, Shallcross, & Twyman, 2009). That is, when required to re-orient in such a space, children used shape to locate a hidden object. This study contradicted previous research that showed that children could only interpret a single axis of symmetry. In the present study, we use a fairly complex space (kite shape) with multiple types of geometric cues (e.g., relative side length, angles, etc.) to address the question of modularity and its prevalence over featural cues.

Modularity in Non-human Animals

The idea of modularity has also been substantiated by other studies on nonhuman animals. A similar disorientation paradigm was conducted on rhesus monkeys in a rectangular room where they were expected to find a hidden food reward. These nonhuman primates continually located the food reward using geometry (i.e., the shape of the space) when there were no featural cues present (Gouteux, Thinus-Blanc & Vauclair, 2001). The search patterns were analogous to those with children (Hermer & Spelke, 1994,1996), in which the correct corner and its rotational equivalent were searched at greater rates than chance. In another part of Gouteux et al. (2001)'s study, they tested the monkeys' ability to reorient using both geometric and featural cues (e.g., a different-colored wall). Although both cues were readily available, geometric information was predominately encoded by the monkeys as they displayed a preference to select the correct corner and its rotational equivalent.

Evidence for a geometric module has also been found in other animals. In two related sets of studies that used pigeons (Vargas, Petruso, & Bingman, 2004) and goldfish (Vargas, Lopez Salas, & Thinus-Blanc, 2004), it was found that information about the shape of a rectangular arena was more readily used when searching for a hidden goal, although the same location could be distinguished using landmarks. Taken together, studies with children and other animal species have been taken as evidence for the exclusive use of geometry even when featural cues are available and useful for specifying location precisely – consistent with the geometric module.

Featural Cues

There is also evidence that contradicts the geometric module. Learmonth, Nadel, and Newcombe (2002) argued against modularity by demonstrating that the size of the experimental space impacted children's use of landmarks. Both a small and large experimental space was used in this study, and it was found that in larger spaces children were actually quite apt to use the blue wall as a landmark to locate the toy; that is, they did not make rotational errors. The authors concluded that perhaps color was most useful to children in larger spaces because that context is more naturalistic in contrast to the unnatural smaller experimental space. It is also suggested that the reason older children use more featural cues is a result of their spatial reasoning skills in which they adapt what they learn about larger spaces to smaller ones. Another study by Learmonth et al. (2001) found more evidence in favor of landmark usage in 18-month-olds, showing that even at younger developmental stages such cues can be used, at least in larger spaces. These results showed the processing of non-geometric information in addition to geometric cues by young children, which served to question the existence of a geometric module.

Geometry and Featural Cues: An Integrative Approach?

Other studies have advocated in favor of a search process that incorporates both geometry and landmarks. A study by Lee et al. (2006) explained search behavior through an initial "modular reorientation process" and an "associative process" that tied particular locations to landmarks. In this process, landmarks are seen as an integral part to search but are still considered secondary. Lee et al.'s concept is also supported by an experiment by Cheng and Gallistel (1984) in which it was shown that rats had a tendency to search for food in two places, the geometrically correct corner or its rotational equivalent but used landmarks prior to digging in order to distinguish the correct corner.

Certain proponents of the geometric module address the developmental changes in reorientation by describing the influence of language. A study by Hermer-Vasquez et al. (1999) demonstrated that proper use of the words "right" and "left" in children allowed them to use both featural and geometric cues. According to this adaptive-combination approach, it would be argued that the use of both featural and geometric cues, in conjunction, is in fact a function of exposure and experience, therefore explaining why older children and adults have the ability to incorporate both types of information.

Another study in adults found that there was a weighted combination of both landmarks and geometry, where the most salient cue was used (Ratcliff and Newcombe, 2008). The salience of a cue, whether geometry or a landmark, is associated with prior exposure, meaning that if a child or an adult has been exposed to more landmarks they will tend to use them more readily or vice versa. When both landmarks and geometry are pitted against each other, the cue that is used is determined by numerous factors, such as the size of the space. For example, in larger spaces, landmarks were preferred and in smaller spaces geometric cues were used to reorient the most, at least in adult participants.

Additionally, research on rats has demonstrated that not only are landmarks not ignored, but that they can even potentiate the learning of geometry (Graham, Good, McGregor & Pearce, 2006). In Graham et al.'s experiment, rats were trained to find a submerged platform in a kite-shaped pool that was constructed from two long and two short walls and with two right-angled corners (where long and short walls met). Throughout the trials, the platform was located at the same right-angled corner. For the experimental group, the walls of this corner were always the same color (black) and the opposite walls were always a different color (white); for the control group, either the color of the pairs of walls varied randomly or the four walls were of the same color. Afterwards, both groups were tested in a pool where all walls were of the same color. These trials showed a stronger tendency for the experimental group to search in the correct corner than the control group, suggesting that learning about the position of the platform relative to the shape of the pool was potentiated when the color of the walls could also be used to indicate where the platform was located. Therefore, being exposed to featural information actually appeared to help the rats process more information about the geometrical space. Graham et al. (2006) concluded that the color of the wall impacted learning about the shape of the geometric space. These findings directly challenge the claim of geometric modularity, which states that learning about a shape is strictly limited to a particular structure in the brain which is unaffected by other stimuli such as featural cues. The current study adapts this paradigm for use with children in order to see whether they are also capable of using similar featural cues.

Present Experiment

The present study borrows from Graham et al. (2006) to address the conflicting theories that exist about the use of both geometry and landmarks in children. Both 3-year-olds (36-47 months) and 4-year-olds (48-59 months) were tested. This experiment aimed to extend previous findings that demonstrated that being exposed to a landmark in a complex space could improve learning about that space. Previous studies have not used a kite-shaped space to test the use of geometric and featural cues in children, adding to the existing literature. The dimensions of the kite were directly proportional to that of Graham et al.'s (2006) experimental space. In this experiment, the corners of the kite-shaped space can be distinguished on the basis of geometry alone. The kite-shaped enclosure also includes aspects of geometry that are common to both rectangles and triangles (see Figure 2). Therefore, this disorientation paradigm can draw links to other studies' findings, which also used those shapes.

The purpose of the study is to investigate whether children can maintain information about the location of a hidden object after being disoriented within a kite-shaped space. Because children were unable to track their movements, they were forced to rely on external spatial information alone, namely, the shape of the surrounding kite (or information about the colors of the walls when available). Black fabric covered two of the walls (the adjacent short and black walls) and served as the landmark information. Search patterns and accuracy determined what information, whether geometric or landmarks, children used in order to reorient. A study by Hermer-Vasquez et al. (2001) found that children used landmarks at the age of 6 years, but this study addressed at what age the ability may start to develop, and by doing so provided an informative developmental timeline. By understanding the developmental advances of these age groups and their use of both geometrical and featural cues, this study addressed whether the processing of these cues varies as a function of age. Previous literature has also used both 3- and 4-year-olds in disorientation paradigms and this study is expected to contribute to those findings by determining what information children more readily use. These age groups have also been known for their vast developmental advances, and because 4-year-olds have had more experience with the world than 3-year-olds, these advances should be more pronounced. This idea would be in accordance with Ratcliff and Newcombe (2008) who have suggested that one of the variables that determines landmark usage was previous experiences with these types of cues.

Method

Participants

There were 32 3-year-olds (16 girls and 16 boys) tested in this study. Participants were between 36 and 47 months of age (M=40.16, SD=8.10). Participants came from different ethnic backgrounds (56.3% Caucasian, 25% African American, 6.3% Asian, 9.4% Two or more races). There were also 16 four year-olds (9 girls and 7 boys) tested.

Participants were between 48 and 59 months of age (M=54.02, SD=2.03). Participants were from different ethnic backgrounds (68.8% Caucasian, 6.3% Hispanic, 12.5% African-American, 6.3% Asian, 6.3% Two or more races). All participants were given a small toy at the experiment's conclusion. Informed consent was obtained from each participant's caretaker.

Materials

Children were tested in a kite-shaped space (see Figure 3). This space was centrally placed inside a larger testing room, which was completely symmetrical. Each wall in the experiment room was covered with canvas. Four identical cylindrical containers were placed inside this enclosure, each in a different corner. The containers were each covered so that each participant could not see its contents. Black fabric was used as the landmark. A small stuffed animal (dog) was used as the object of search. A video camera was suspended from the center of the room's ceiling, which was used to record the experiment.

Design

We examined children's search behavior as they looked for a hidden object in the kite-shaped space. The current task involved hiding a toy in a corner of the enclosure, spinning the child around (so that disoriented), and then having the child search for the toy. Each participant completed four test trials in each of the following conditions, for a total of eight trials.

Manipulations:

Landmark Condition

In the landmark condition, black fabric covered one of the kite's short walls and the adjacent long wall that together form a right angle, following previous research by Graham et al. (2006).

No Landmark Condition

In the no landmark condition, all the walls in the kite-shaped enclosure were identical in color.

For a given participant, the toy was hidden in a single location throughout the experiment. Across subjects, the order of the tasks (landmark first vs. no landmark first), the location of the black landmark (two locations), the wall the child faced after disorientation (four locations) and the location of the hidden toy (four locations) were counterbalanced. The wall that the child faced was randomized within each condition, with each faced twice across both conditions.

Procedure

When the child became comfortable with the experimenter they were taken into the disorientation room. Once in this room, the experiment began. The child was asked to stand in the middle of the kite-shaped enclosure and the experimenter pointed to each wall and indicated its color regardless of the condition (landmark first vs. no landmark first). Then the child was introduced to the game by the experimenter saying: "Now we are going to play hide and seek. My puppy likes to hide right in here and you are going to help me find the puppy on the first try." The experimenter hid the toy while the child watched.

The parent was then signaled by the experimenter to enter the kite-shaped enclosure and proceeded to disorient the child by picking him/her up and spinning around three to four times while covering the child's eyes. The experimenter walked around the kite-shaped enclosure while the child was being disoriented, so that they would not serve as an additional landmark. After two rotations, the experimenter showed the parent where to place the child. The experimenter predetermined the wall that the child faced so that throughout the two conditions the child faced each of the kite-shaped enclosure's walls twice, once in each set of trials. The experimenter always stood at the wall opposite that faced by the child.

When the child's eyes were uncovered (after being spun around), he or she was instructed to search for the hidden toy. If the children found the toy on their first attempt, they moved onto the subsequent trial and the experimenter repeated the original instructions. If the participant searched at the incorrect corner, the experimenter said: "The puppy isn't in there. Try looking for the puppy again." Each subject was allowed to search as many corners as necessary to find the toy. If the child pointed to a corner, the experimenter encouraged them to search at that particular corner. If the child refused to search for the toy, or after several unsuccessful attempts, the experimenter showed the child where the toy was hidden. Trials were repeated following the same instructions.

Once the first set of trials was completed, the subject and parent were escorted out and the black fabric was either put on or removed from the walls. If the landmark trials came first then the following set of trials were the no landmark trials and vice versa. Once the appropriate condition was properly set-up, the experimenter brought both the parent and subject into the room again. The second set of trials began when the experimenter once again pointed to each wall and indicated its color.

As is typical in these types of experiments, all the choices made by children were recorded, but only their first choice on each trial was used in subsequent data analyses.

Results

Accuracy scores were computed for each participant, which was the percentage of total correct searches within each set of four trials (landmark trials vs. no landmark trials). An Analysis of Variance (ANOVA) was conducted using accuracy scores as the dependent variable. This analysis included condition (within-subjects: landmark trials, no landmark trials), order (between-subjects: landmark trials first vs. landmark trials second), hiding location (between-subjects: A, B, C, or D; see Figure 2 for layout of corners), and age (between-subjects: 3- or 4-year-olds) as the independent variables. The ANOVA revealed a significant interaction between condition and order for the combined group of 3- and 4-year-olds, $F(1, 32) = 8.570$, $p = .006$. This two-way interaction is the main interaction of interest (see Figure 4), consistent with the predictions discussed in the Introduction. In the landmark trials, children's mean performance was 37.5% (SD = 30.40) when presented with these trials first (i.e., landmark trials first) and 46.88% (SD = 31.55) when given these trials were presented second (i.e., landmark trials second). Comparison of these two conditions revealed that they did not differ statistically from each other, $F(1, 46) = 1.099$, $p = .30$, suggesting that performance on the landmark trials did not depend on the order they were received. In the no landmark trials, children's mean performance was 27.08% (SD=32.064) when presented with these trials first (i.e., no landmark trials first) and 44.79% (SD=29.469) when presented with these trials second (i.e., no landmark trials second). The mean performances were statistically different from each other, $F(1,46) = 3.968$, $p = .05$, suggesting that, unlike landmark trials, performance in the no landmark trials depended on the order they were received.

Additional comparisons to the chance level of 25% revealed that children performed significantly better in the landmark trials when these trials were presented second ($t(23) = 3.397$, $p = .002$) and performed significantly better in the no landmark trials when these trials were also presented second ($t(23) = 3.290$, $p = .003$).

The ANOVA also revealed a main effect of hiding location. This analysis showed that hiding location significantly impacted search performance, $F(3, 32) = 5.136$, $p = .005$. An additional Univariate Analysis of Variance indicated that hiding location particularly impacted search in the in the no landmark trials, $F(3, 44 = 5.219$, $p = .004$ but did not in the landmark trials, $F(3, 44) = .873$, $p = .462$. Post hoc contrasts were conducted to compare accuracy in locating the hidden toy in each of the corners and found that in the no landmark trials performance in corner C was significantly better than corner A (see Figure 3), $p =.002$, suggesting that some corners are easier for children to use for re-orientation than others. To compare performance at each corner as a function of condition, this analysis (with difference scores) was conducted (see Figure 5).

The main ANOVA also revealed a main effect of age. This analysis showed that age significantly impacted search performance, $F(1, 32) = 7.087$, $p = .012$. An additional Univariate Analysis of Variance found 4-year-olds' mean performance to be significantly better than that of 3-year-olds in the landmark trials, $F(1, 46) = 5.397$, $p = .025$. This was not the case in the no landmark trials, where mean performance across groups did not significantly differ, $F(1, 46) = 2.143$, $p = .150$.

The main ANOVA also indicated a significant four-way interaction across condition, order, hiding location, and age group, $F(3, 32) = 3.245$, $p = .035$. Post-hoc tests determined that most of the interaction was driven by the variability in performance across the 3-year-olds who displayed a significant three-way interaction between condition, order, and hiding location, $F(3, 24) = 3.84$, $p = .022$. The 4-year-olds, however, showed only interactions between condition and order. The interaction between the three factors was also not significant, $F(3,8) = 1.420$, $p = .307$. This means that although search in the correct corner improved in the no landmark condition after receiving the landmark first (order), this effect was magnified in certain hiding locations, but only for the 3-year-olds. Landmarks can probably further disambiguate corners that tend to be easier for 3-year-olds, like C, but hinder performance at the other locations. The 4-year-olds do not demonstrate this interaction perhaps because they tended to do better overall at all the corners.

Discussion

The results of the current experiment support and extend previous research by Graham et al. (2006) on rats. By testing children in a task similar to the one used by Graham et al. (2006) we have further evidence in favor of the use of featural cues when reorienting. Across both 3- and 4-year-olds, there was improvement in performance in using the geometry (no landmark trials) when they were exposed previously to featural cues (landmark trials). This means that learning about the shape of the enclosure was affected by the color of the walls making that shape. Similarly, findings of the current study are supported by Twyman, Friedman, and Spetch's (2007) paradigm, which also revealed that children readily use featural cues. In their study, a yellow wall or a 1½ inch gap between the floor and the fabric of the white wall were used as landmarks by children in a rectangular shape after 4 trials of disorientation alone, which is equal to the amount of landmark trials in the current experiment.

Taken together, the present, and related, findings contradict earlier research by Hermer and Spelke (1994, 1996) who argued that geometric information alone was attended to regardless of the presence of featural cues. The use of landmarks in children at this early age may question the validity of the language hypothesis brought forth by previously mentioned studies by Hermer and Spelke (1996) and Hermer-Vasquez et al. (2001) that have proposed that the use of featural cues is related to advancements in language. The current study suggests that 3- and 4-year-olds are capable of using these cues independent of these developments, which would mirror findings in avian species, such as chicks and pigeons (Vallortiga, Zanforlin, & Pasti, 1990; Spetch & Edwards, 1988; Spetch, Cheng & Mondloch, 1992) who have no language mechanism but are still capable of integrating featural cues. Moreover, children in this study are capable of using featural cues after only a few trials with a landmark disputing various claims suggesting that modularity cannot be overcome at this young age so easily. Further investigation would be needed to further dispute the language hypothesis in future studies.

The present study also found age-related differences between 3- and 4-year-olds in their search performance. It is important to note that 4-year-olds performed significantly better than the 3-year-olds in the trials where the landmark was present, which may mean that previous experiences with landmarks improve their performance. This echoes previous ideas of Ratcliff and Newcombe (2008) who believe that more exposure to featural cues increases their use in disorientation tasks.

Although featural cues did improve performance in the no landmark trials, we must acknowledge that there was also some improvements in performance when children were presented with any set of trials second regardless of having a landmark prior. The improvement was shown by performances in the second set of trials, which were significantly different from chance. This could be indicative of a practice effect, where children simply perform better in the next set of trials because they are getting better at the task. This seems unlikely, however, given that there was no significant improvement for the second landmark trials compared to the first landmark trials. In addition, effects of hiding location suggest that practice alone may not explain the order effect. If better performance was simply due to practice, performance at each corner should have improved at equal rates, but, instead, these rates were variable. For example, we found the greatest differences in accuracy at corner C during the no landmark trials compared to the landmark trials. The other corners, in contrast, showed less variability by condition. This difference in accuracy across the corners was probably driven by the 3-year-olds who are more strongly impacted by the main effect of hiding location. This indicates that perhaps landmarks make easier hiding locations, like C, more distinguishable.

It was also clear, after close observation, that children were not simply selecting corners that were closest to them after disorientation. If they were choosing based on proximity alone, performance would have been at chance and that was not always the case. This was also substantiated by the shock some children had when they searched in the incorrect corner. It seems as though during search all other corners, except C, were easily confused. Looking back at the schematic of the angles (see Figure 3), it may be that corners A, B, and D are all clustered at the top of the kite-shaped region making each hard to distinguish from each other. This is in accordance with previous ideas of overshadowing, which claim that when there are multiple cues, such as geometric and featural cues, there is more difficulty in encoding the cues (Mackintosh, 2003; Spetch, 1995). Therefore, certain cues are easier to encode in isolation of each other. Overshadowing is a phenomenon that has largely been shown with landmarks (at the correct search location) overshadowing other present landmarks. Examples of overshadowing were found in an experiment by Spetch (1995), which tested both pigeons and humans, and revealed that a landmark on a computer monitor at the target location overshadowed other landmarks in the experimental space. Perhaps the competing featural and geometric cues did not facilitate the encoding of the available information and instead hindered each child’s performance. Since the kite is a very complex shape that has many geometric cues available, perhaps additional featural cues did not allow them to perform at their fullest capacity.

In order to further investigate the possible presence of a practice effect and to see whether in fact landmarks helped potentiate learning it would be important to test a bigger sample size and have a follow-up experiment where we compared performance in both conditions to a control group who are just exposed to 8 no landmark trials. By creating a separate control group, comparisons between subjects could directly rule out a practice effect. Future studies may also consider using more stable landmarks throughout the landmark trials in order to improve performance afterwards in the no landmark trials, which would be in accordance with ideas of Learmonth et al. (1998). Learmonth et al. found that when using stable landmarks such as a bookcase and door in a rectangular space, children between 18-24 months were more likely to search in the correct corner, rather than its rotational equivalent, at rates above chance. Similarly, Wang, Hermer, and Spelke (1999) also found that other landmarks, such as a bump in a square room, could be used by both 18- and 24-month-olds to distinguish a correct corner despite their failed use of a colored wall.

The current experiment suggests positive implications of landmark use and how it may be used in the reorientation process. Despite previous claims of an encapsulated view of modularity, this study has found a form of improvement when children were exposed to a landmark prior to no landmark trials where only the geometry of the kite-shape space was available. Since children did not ignore featural cues, it puts the modularity view into question. Evidence from this experiment also allowed us to take an integrative stance where the belief is that children can encode both geometric and featural cues. Since there were improvements in performance when the landmark came second in the landmark trials, perhaps the original geometric information the child picked up prior was useful in the second set of trials and the same can be said of the featural information used to facilitate learning when faced with the no landmark trials afterwards. It may be that children use shape on some trials to reorient while on other trials they are using landmarks depending on the salience of the cue to which they were exposed to first. Ratcliff and Newcombe (2008) also support this idea because they have findings that suggest that both featural and geometric information are used interchangeably depending on prior experiences and exposure to such cues. Similar to the findings of Learmonth et al. (2002), children at this developmental stage are perhaps integrating both geometric and featural cues.

The results of the current study have allowed us to speculate about the reasons why featural cues improve encoding of the geometry. These featural cues may have helped outline an axis of symmetry within the complex experimental space. Perhaps this primary axis of symmetry allowed children to interpret the kite-shaped space through other more familiar shapes, such as triangles and rectangles (see Figure 2), which are spaces where children and even rats were able to encode the geometry (Benhamou & Poucet, 1998; Huttenlocher & Vasilyeva, 2003). Dividing the space along this axis of symmetry may have ultimately helped children keep track of the various corners and resulted in their improvement in performance in using the geometry (no landmark trials) when they were exposed previously to featural cues (landmark trials).

Graham et al. (2006)'s experiments and the current study have revealed that learning about the shape of a surrounding space is improved by the use of featural cues. This casts doubts on previous studies by Cheng (1986) and Gallistel (1990) that have argued in favor of a modular view. The current experiment also challenges previous beliefs about the geometric module in which geometric information is processed in isolation of all other cues. Since children have been capable of using featural cues to reorient, important questions regarding the theoretical implications of this encapsulated module will have to be addressed in the future.

References

Benhamou, S., & Poucet, B. (1998). Landmark use by navigating rats (Rattus norvegicus): Contrasting geometric and featural information. *Journal of Comparative Psychology*, *112*, 317-322.

Cheng, K. (2005). Reflections on geometry and navigation. *Connection Science*, *17*, 5-29.

Cheng, K., & Gallistel, C.R. (1984). Testing the geometric power of an animal's spatial representation. In H.L. Roitblat, T.G. Bever, & H.S. Terrace (Eds.), Animal cognition. Hillsdale, NJ: Lawrence Erlbaum Associates (pp. 409-423).

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

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

Graham, M., Good, M. A., McGregor, A., & Pearce, J. M. (2006). Spatial learning based on the shape of the environment is influenced by properties of the objects forming the shape. *Journal of Experimental Psychology: Animal Behavior Processes, 32,* 44–59.

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

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

Hermer-Vazquez, 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*, 263-299.

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

Huttenlocher, J., & Vasilyeva, M. (2003). How toddlers represent enclosed spaces. *Cognitive Science, 27*, 749–766.

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

Learmonth, A.E., Newcombe, N.S., & Huttenlocher, J. (1998). Disoriented children use landmarks as well as geometry to reorient. Paper presented at the meeting of the Psychonomics Society, Dallas, TX.

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

Lee, S.A., Shusterman, A., & Spelke, E.S. (2006). Reorientation and landmark-guided search by young children. *Psychological Science*, *17*, 577-582.

Lourenco, S.F., Huttenlocher, M., & Vasilyeva, M. (2005). Toddlers' representations of space: The role of viewer perspective. *Psychological Science*, *16*, 255-259.

Mackintosh, N.J. (2003). Pavlov and associationism. *The Spanish Journal of Psychology*, *6*, 177-184.

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*, *12*, 1-8.

Ratcliff, K.R., & Newcombe, N.S. (2008). Reorienting when cues conflict: Evidence for an adaptive combination view. *Psychological Science*, *19*, 1301–1307.

Spetch, M. L. (1995). Overshadowing in landmark learning: Touch- screen studies with pigeons and humans. Journal of Experimental Psychology: Animal Behavior Processes, 21, 166-181.

Spetch, M.L., Cheng, K., & Mondloch, M.V. (1992). Landmark use by pigeons in a touch-screen spatial search task. *Animal Learning and Behavior*, *20*, 281-292.

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

Vallortigara, G., Zanforlin, M., & Pasti, G. (1990). Geometric modules in animals' spatial representations: A test with chicks (Gallus gallus domesticus). *Journal of Comparative Psychology*, *104*, 248-254.

Vargas, J. P., Lopez, J. C., Salas, C., & Thinus-Blanc, C. (2004). Encoding of geometric and featural spatial information in goldfish (Carassius *auratus). Journal of Comparative Psychology, 118,* 206–216.

Vargas, J. P., Petruso, E. J., & Bingman, V. P. (2004). Hippocampal formation is required for geometric navigation in pigeons. *European Journal of Neuroscience, 20,* 1937–1944.

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

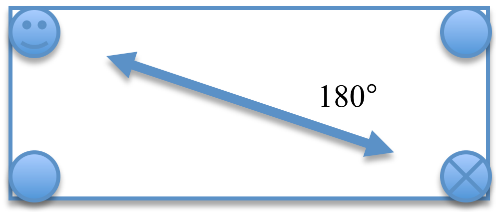


Figure 1. The rotational error is represented by the “X” and the correct corner by ☺, which is where the toy is hidden. If children search the correct corner and its geometric equivalent above chance, this demonstrates that geometric cues are being used to locate the object.

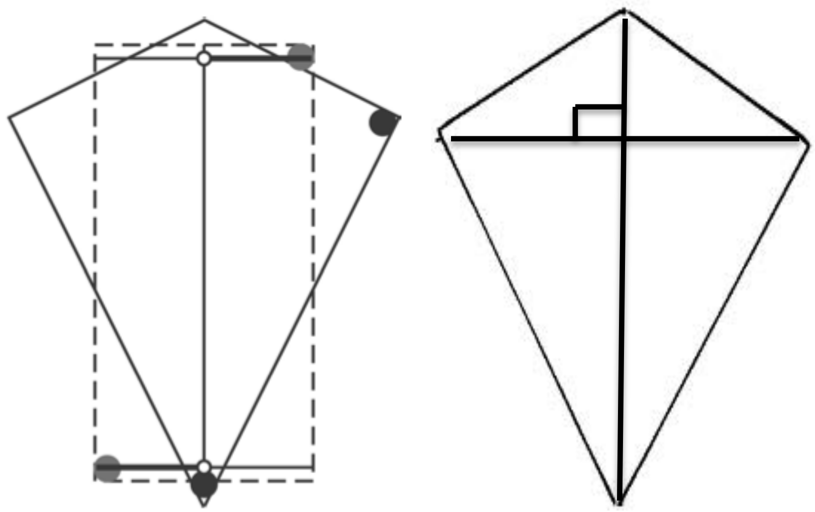


Figure 2. The corners in a kite-shaped region are similar to ones in rectangular and triangular spaces. Adapted from “Reflections on geometry and navigation” by K. Cheng, 2005, *Connection Science*, *17*, p. 12.

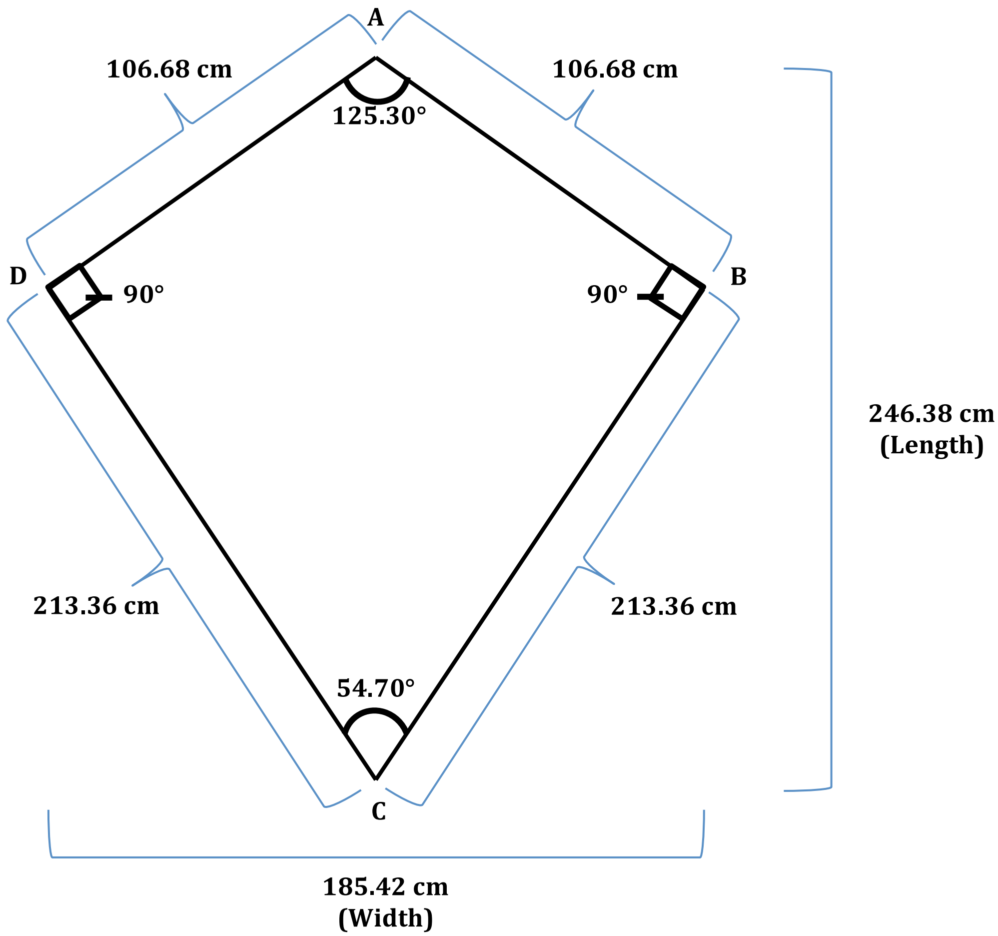
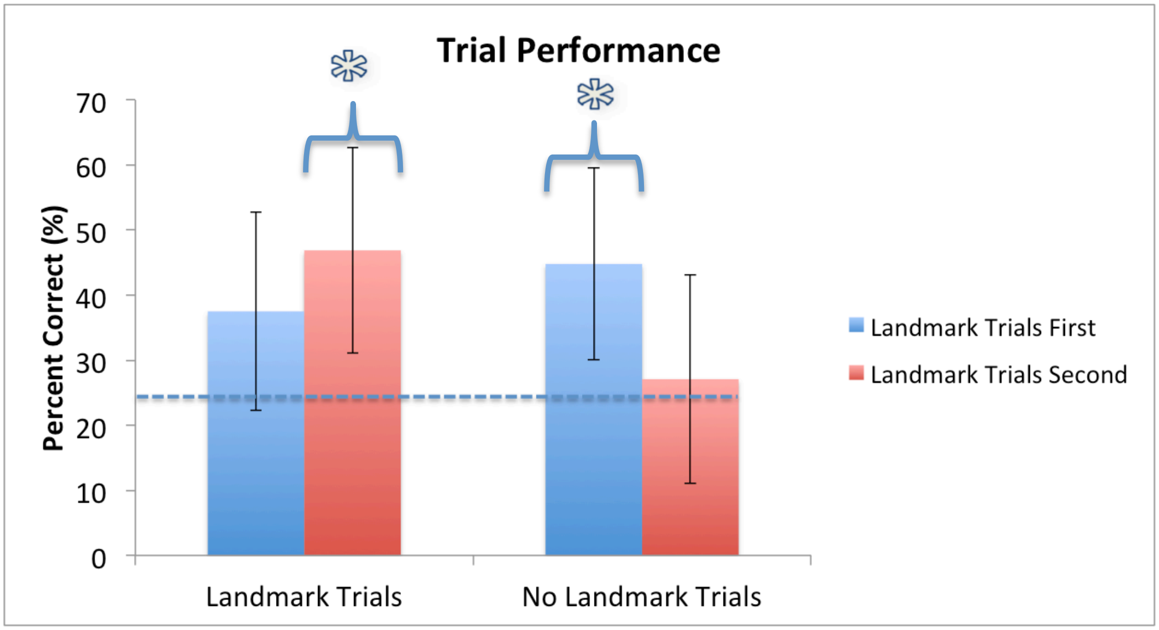


Figure 3. Kite-shaped enclosure used in the present study.



✻ *p*<.01

Figure 4. Performance was compared in the landmark trials and no landmark trials. The significant differences presented are differences compared to chance, 25%, also represented by the dashed line.

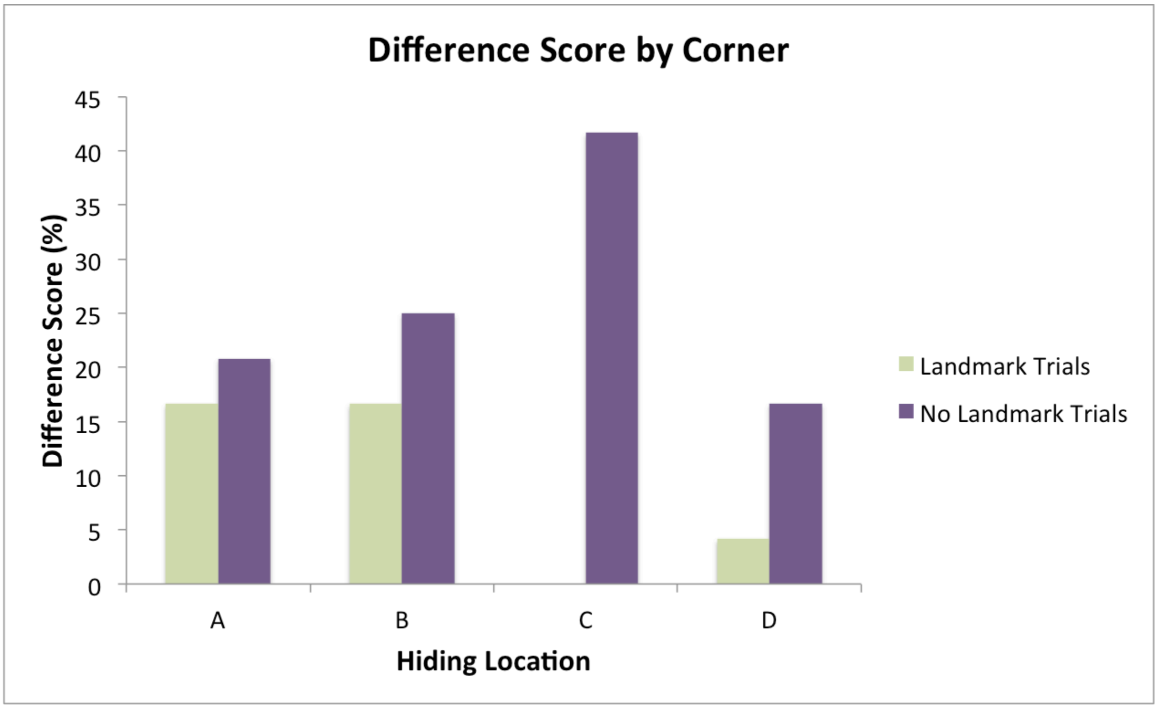


Figure 5. Difference scores [Absolute value (performance in landmark first-performance in landmark second)] are compared across corners in the landmark and no landmark trials.