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PAPER

Early sex differences in weighting geometric cues

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Abstract

When geometric and non-geometric information are both available for specifying location, men have been shown to rely more heavily on geometry compared to women. To shed insight on the nature and developmental origins of this sex difference, we examined how 18- to 24-month-olds represented the geometry of a surrounding (rectangular) space when direct non-geometric information (i.e. a beacon) was also available for localizing a hidden object. Children were tested on a disorientation task with multiple phases. Across experiments, boys relied more heavily than girls on geometry to guide localization, as indicated by their errors during the initial phase of the task, and by their search choices following transformations that left only geometry available, or that, under limited conditions, created a conflict between beacon and geometry. Analyses of search times suggested that girls, like boys, had encoded geometry, and testing in a square space ruled out explanations concerned with motivational and methodological variables. Taken together, the findings provide evidence for an early sex difference in the weighting of geometry. This sex difference, we suggest, reflects subtle variation in how boys and girls approach the problem of combining multiple sources of location information.

Introduction

While it is not particularly controversial that sex differences exist on various spatial tasks (for review, see Halpern, Benbow, Geary, Gur, Hyde & Gernsbacher, 2007), there is much controversy over their origins and meaning (e.g. Ceci & Williams, 2007). Fiercely debated have been questions such as: do sex differences in performance reflect underlying (perhaps innate) spatial abilities, or, rather, are performance differences due to other factors such as problem-solving approach, which, at least initially, need not be related to ability? Such questions have proven difficult to answer, especially in adults for whom early developmental predispositions or preferences for particular strategies could have led to later sex differences in spatial ability.

Perhaps the most widely reported of these differences concerns performance on mental rotation tasks. When making judgments about objects or scenes presented from different perspectives, men are generally faster and more accurate than women (e.g. Terlecki, Newcombe & Little, 2008; Voyer, Voyer & Bryden, 1995). This so-called male advantage emerges early in development, with sex differences documented in preschoolers (Levine, Huttenlocher, Taylor & Langrock, 1999; Rosser Ensing, Glider & Lane, 1984) and even infancy (Moore & Johnson, 2008; Quinn & Liben, 2008). While early-developing sex differences could certainly reflect innate mental rotation abilities (Geary, 1998; Kimura, 2000), even the earliest differences might be rooted in experiences with activities that promote mental rotation or preferences for particular problem-solving strategies (Casey, 1996; Spelke, 2005). For example, females may be more sensitive than males to the featural properties of stimuli, possibly relying on analytic (point-by-point) comparisons rather than holistic processes of mental alignment to solve mental rotation problems (Heil & Jansen-Osmann, 2008; Kail, Carter & Pellegrino, 1979). A common assumption is that females rely on featural comparisons, which may be particularly prone to error, because they are less proficient at holistic transformations. The problem with this assumption is that many other factors are known to affect strategy selection, including differences in familiarity and experience with task-related stimuli (Bethell-Fox & Shepard, 1988; Smith & Dror, 2001).

Sex differences also exist on location tasks in which people give directions or plan routes. On these tasks, there is typically more than one type of information available for specifying where target objects or places are located. One type can be considered *geometric*, and includes distance/length and angle (either in isolation or combined as overall shape), as well as directional cues. Another type is *non-geometric* and includes landmarks,

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which, when associated directly with the target location, are known as beacons. Although adults of both sexes tend to favor simple landmarks over geometry, men make more reference to distance (e.g. '5 miles') and cardinal direction (e.g. 'northeast') compared to women (Galea & Kimura, 1993; Saucier, Green, Leason, MacFadeen, Bell & Elias, 2002; Ward, Newcombe & Overton, 1986). Using virtual reality, Chai and Jacobs (2010) showed that whereas men and women both remembered locations marked by positional (beacon) information, only men encoded geographical slant (see also Nardi, Newcombe & Shipley, 2011). Similarly, Sandstrom, Kaufman and Huettel (1998) showed no sex difference in the use of landmarks to locate a hidden platform, but greater reliance on the geometry of the surrounding (trapezoidal) space by men than women (see also Woolley, Vermaercke, Op de Beeck, Wagemans, Gantois, D'Hooge, Swinnen & Wenderoth, 2010).

Why might the sexes differ in their reliance on geometry? One possibility is that women are less proficient than men at processing geometric cues such as cardinal direction and the shapes of surrounding spaces. An alternative possibility is that men and women approach the problem of representing location differently (Kelly & Bischof, 2005; Schmitzer-Torbert, 2007; Ward *et al.*, 1986), with women placing relatively less weight on geometry, at least when non-geometric information is also available. There are generally multiple sources of information to choose from in the physical environment and a critical first step in solving any location problem is the selection and weighting of information (Cheng, Shettleworth, Huttenlocher & Rieser, 2007; Gallistel, 1990). While sex differences in the weighting of geometric cues could arise because of deficiencies with processing these cues, there are various other factors that might affect weighting (independent of ability), including familiarity and perceived salience of the relevant location information (Kelly & Bischof, 2008; Newcombe & Huttenlocher, 2006).

Current study

The current study concerns the representation of location in young children (18–24 months). Given the many challenges of interpreting sex differences in adulthood, studies designed to examine location representation early in development may shed insight on the origins and meaning of spatially related sex differences. Here we asked how boys and girls use geometry to find a hidden object when simple non-geometric information is also available. Serving as geometry was a rectangular-shaped space. Serving as non-geometric information was a beacon (distinctive container or flag), which directly marked the location of the hidden object (i.e. target location).

Our task included a disorientation procedure, which has been used previously to show that even young children are capable of representing the geometry of surrounding spaces, such as a rectangular room (e.g. Hermer & Spelke, 1994; Learmonth, Newcombe & Huttenlocher, 2001). Children in these studies are shown the hiding of an object at one of the corners of a space. They are then disoriented by being spun around several times (with eyes covered), and finally allowed to search for the hidden object. The disorientation procedure prevents children from relying on the egocentric strategy of keeping track of the target location in relation to their own bodies (e.g. in front and to one's left). In a rectangular space, children mostly search at the corner where the object is actually hidden and the corner diagonally opposite it, both of which are identical with respect to the relative positions of the long and short walls (e.g. shorter wall to the left of longer wall), and both of which are geometrically distinguishable from the other two corners in the space (e.g. shorter wall to the right of longer wall).

Non-geometrical information, such as a wall of different color in a rectangular space, is used less reliably by children (for review, see Cheng & Newcombe, 2005). Despite the added predictive value, children often rely exclusively on geometry following disorientation, especially in small spaces. Non-geometric information, however, can vary in its association to the target location, and, importantly, this may affect location representation (Kelly & Spetch, 2004; Lee, Shusterman & Spelke, 2006; Shettleworth & Sutton, 2005). In the experiments below, the target location was *directly* marked by a beacon, and even infants have been shown to use beacon information to locate objects (Bremner, 1978; Bushnell, McKenzie, Lawrence & Connell, 1995).

Borrowing from paradigms used with nonhuman animals (e.g. Chiandetti, Regolin, Sovrano & Vallortigara, 2007; Kelly, Spetch & Heth, 1998; Wall, Botly, Black & Shettleworth, 2004), our task consisted of two phases. In the first phase, a beacon and geometry were both available for specifying the location of the hidden object. The second phase featured a transformation, which altered the relation between beacon and geometry. One type of transformation made the beacon uninformative, leaving only geometry for predicting the target location (Experiment 1). Another transformation created a conflict between beacon and geometry, such that each predicted a different location (Experiments 2A and 2B). By manipulating the relations between beacon and geometry, we could examine more fully how boys and girls combine different types of location information.

Particularly relevant to the current study is that sex differences have *not* been previously reported on disorientation tasks (Hermer & Spelke, 1994; Hupach & Nadel, 2005; Huttenlocher & Vasilyeva, 2003; Learmonth *et al.*, 2001; Learmonth, Newcombe, Sheridan & Jones, 2008; Lourenco & Huttenlocher, 2006; Lourenco, Huttenlocher & Vasilyeva, 2005). When only geometry is available (e.g. rectangular space with no landmark) or when only geometry is used (e.g. rectangular space with a different-colored wall), boys and girls perform comparably, relying on geometry at equivalent levels for solving the location problem. That boys and girls are both capable of representing geometry, and that they have been shown to use geometry at comparable levels would play a critical role in the interpretation of the current findings. If boys and girls differed in how they used geometry in the presence of a beacon, we could rule out explanations concerned with early sex differences in competence surrounding the processing of geometry.

Experiment 1

In this first experiment, we examined children's search responses when beacon information and geometry were both available for localizing a hidden object (Phase 1), and then following a transformation in which only geometry was available (Phase 2). Children were tested inside a rectangular space where they were shown that a toy was hidden at one of the corners in a distinctive container (beacon). Given the beacon's direct link to the hidden object (e.g. Kelly & Spetch, 2004; Lee *et al*., 2006) and based on work with nonhuman animals (e.g. Wall *et al*., 2004), we predicted that most children (regardless of sex) would use beacon information, when available (Phase 1), to locate the hidden object.

It was less clear how children would treat geometry in the presence of a beacon. On the one hand, beacon information uniquely specifies the target location, eliminating the need to encode geometry altogether, at least in Phase 1. On the other hand, geometry is the only way to solve the location problem if the beacon becomes unavailable (Phase 2), essentially serving as protection against the loss of beacon information. Furthermore, there is evidence that geometry may be prepotent, used at the exclusion of non-geometric information under some conditions (Cheng & Newcombe, 2005). Given the potential for variation in problem-solving approach, we predicted that sex differences might be observed on our task, and as has been shown for mental rotation (e.g. Quinn & Liben, 2008), that they would mirror those later in life, with boys relying more heavily on geometry than girls.

Method

Participants

Thirty-two children (16 girls) between 18 and 24 months (girls: $M = 20.9$, $SD = 1.7$; boys: $M = 20.6$, $SD = 1.8$) participated. Four additional children were excluded for failing to keep their eyes covered during the disorientation procedure. Children were given a small gift for participating, and experimental procedures met ethical guidelines.

Materials and procedure

Children were tested individually inside a rectangular space (all brown), roughly the size of a large playpen (as in Lourenco *et al*., 2005; length: 114.3 cm, width: 76.2 cm, height: 43.2 cm; see Figure 1). This space was positioned at the center of a large (opaque) circular enclosure (diameter: 3.9 m, height: 2.3 m), serving to conceal objects in the surrounding room. Along with the parent and experimenter, the child entered the circular enclosure through an opening in the curtain, which left no visible markings when shut. The rectangular space included a container (height: 28 cm, diameter: 11.5 cm) at each corner. On each trial, children stood inside the rectangular space and watched as the experimenter hid a desirable toy (e.g. small plush dog) in one of the containers. The experimenter always stood outside the rectangular space, reaching in to hide the toy. Following the hiding event, the parent stepped inside the rectangular space (previously standing outside it), picked the child up, covered his/her eyes, and spun him/her around, completing 4–6 revolutions. After the disorientation procedure, children were placed in front of one of the

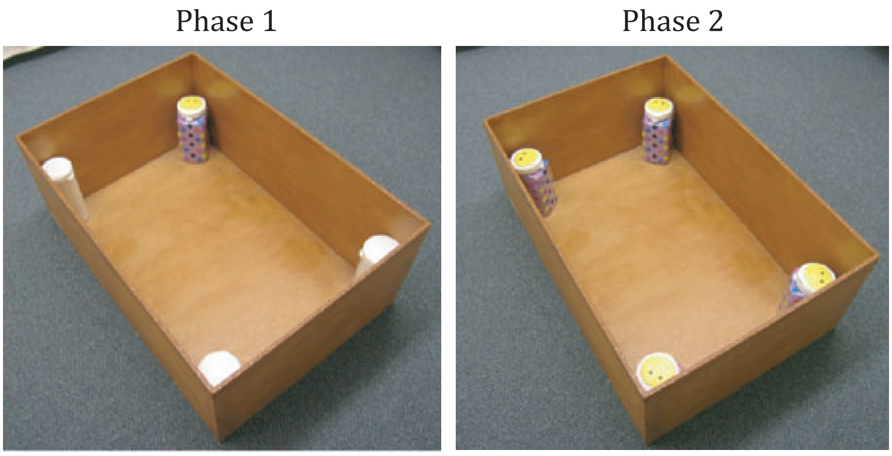

Figure 1 *Left: Photograph of the rectangular space (length: 114.3 cm, width: 76.2 cm, height: 43.2 cm) used in the current study. In Phase 1 of Experiments 1 and 2A, this space included a distinctive container as the beacon at one of the corners. Right: Photograph of the space during Phase 2 of Experiment 1.*

walls (a different wall on each trial, randomly determined) and encouraged to find the hidden toy. The experimenter and parent always stood outside the rectangular space during search, moving around so as not to serve as a landmark. Parents were instructed not to influence children's responses; all complied. Children searched for the toy until they found it, but as in previous studies, only their first response was scored. A square-shaped surveillance camera, hanging from the center of the ceiling, was used to record the experiment.

The task consisted of two phases. Phase 1 included beacon information – a distinctive container, unique in color and pattern (see Figure 1, left). The other three containers were identical to each other (all white, no pattern). The toy was always hidden at the corner with the beacon; corner counterbalanced across children. Because the beacon remained in the same corner on all of these trials, geometry was also available for localization (e.g. corner with shorter wall to the left of longer wall). There were four trials in Phase 1. Phase 2 followed and involved a transformation; as children were being disoriented, the experimenter replaced the three identical (non-beacon) containers with ones that looked just like the beacon (see Figure 1, right). Children were given two trials in Phase 2.[1]

Results

Accuracy scores were calculated for each child. In Phase 1, responses were scored as correct if children searched at the target corner (i.e. the corner with the distinctive container). Phase 1 scores could range from 0 to 4 correct. In Phase 2, accuracy scores were based on geometry (i.e. the rectangular space); responses were correct if children searched at either of the geometrically appropriate corners (i.e. the target corner or the corner diagonally opposite it). Both corners are considered correct because they are indistinguishable with respect to geometry (e.g. shorter wall to the left of longer wall). Phase 2 scores could range from 0 to 2 correct.

Preliminary analyses on accuracy scores revealed no significant effects of age (ps > .3) or counterbalanced corner (ps > .1) during either phase. Thus, these variables were not included in subsequent analyses.

Phase 1

Children of both sexes searched at the target corner significantly above chance [25%; girls: $t(15) = 15.81$; boys: $t(15) = 6.58$; ps < .0001] and significantly more often than the geometrically equivalent corner [girls: $t(15) = 16.75$; boys: $t(15) = 5.41$; ps < .0001; Figure 2, top]. An analysis of variance (ANOVA) on accuracy scores, with sex as the between-subjects variable, revealed a significant main effect of sex, $F(1, 30) = 5.87$, $p < .05$, $d = 0.86$; girls searched at the target corner more than boys (Figure 2, top). Additional analyses revealed that when search was not directed at the target corner, boys went to the geometrically equivalent corner (11/20 trials, $p < .05$, binomial test, one-tailed) more than chance (33.33%), but girls did not (2/8 trials, $p > .4$), suggesting that boys were more influenced by geometry than girls, a possibility examined more directly in Phase 2 (where the beacon was made uninformative).

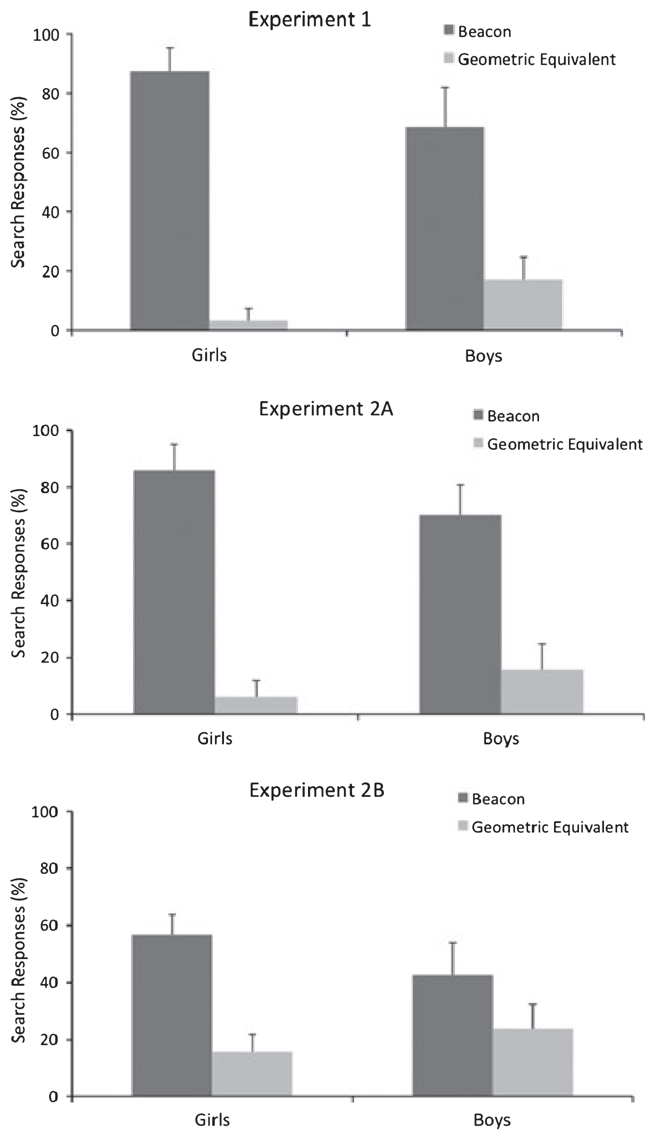

Figure 2 *Mean percentage (and standard deviation) of search responses at the target corner (marked by the beacon) and geometrically equivalent corner during Phase 1. Search responses are presented separately for girls and boys in Experiments 1 (top), 2A (middle), and 2B (bottom).*

[1] As is typical with location tasks that employ transformations (e.g. Ratliff & Newcombe, 2008; Wall et al., 2004), Phase 2 in the current study consisted of fewer trials (two trials in Experiment 1 and one trial in Experiments 2A, 2B, and 3) than Phase 1. We designed the 2nd phases to probe children's representations of location during the initial phase, not learning or flexibility to changing conditions. We thus included only one or two trials in Phase 2 to ensure that children's performance reflected encoding during Phase 1.

Phase 2

Analyses of Phase 2 revealed that boys (M = 75%, SD = 25.8%) searched at the geometrically appropriate corners more than girls (M = 53.1%, SD = 28.7%), $F(1, 30) = 5.14$, $p < .05$, $d = 0.80$, and only boys [$t(15) = 3.87$, $p < .01$] searched at these corners significantly above the chancel level of 50% [girls: $t(15) = .44$, $p > .6$].[2] Analyses comparing search at the target corner to the geometrically equivalent corner revealed no significant differences between these corners for either sex ($ps > .3$), ensuring that children were fully disoriented, and confirming that greater search at the geometrically appropriate corners by boys than girls reflected a sex difference in the use of geometry rather than the extent of disorientation.

Discussion

When a beacon and geometry were both available for specifying location (Phase 1), girls and boys searched reliably for the hidden object at the target location, going to the corner marked by the beacon more than the other corners, including the geometric equivalent. While developmental psychologists have long pointed to the early predominance of topologically based representations of location (Liben, Moore & Golbeck, 1982; Piaget & Inhelder, 1967), more recent research suggests that geometry is cognitively privileged, at least under conditions of disorientation (Cheng & Newcombe, 2005). Studies showing that geometry is used to the exclusion of non-geometric information, however, generally include landmarks (e.g. different-colored wall), which are computationally more demanding than beacons (Gallistel, 1990; Shettleworth & Sutton, 2005). Whereas a beacon specifies the target location by being spatially contiguous with it, landmarks involve a less direct link. Knowing, for example, that the hidden object is adjacent to a different-colored wall in a rectangular space is not sufficient for specifying its location (see Figure 3); sense (i.e. left/right) is also needed to distinguish the two corners in adjacent positions. A beacon may be used more reliably by children because additional cues are not required to disambiguate the target location from other possibilities.

While both girls and boys clearly favored beacon information over geometry, this was more strongly the case for girls. What might account for this? We suggest that the answer may lie in the other sex difference observed in this experiment; namely, greater use of geometry by boys than girls. When not searching at the target location during Phase 1, boys went to the geometrically equivalent corner more than girls, and when the beacon was no longer available during Phase 2, only boys searched at the geometrically appropriate corners. Search responses during both phases of the task suggest that boys weighted geometry more heavily than girls, which may have led to their reduced reliance on the beacon (see Experiment 3 below for an alternative possibility).

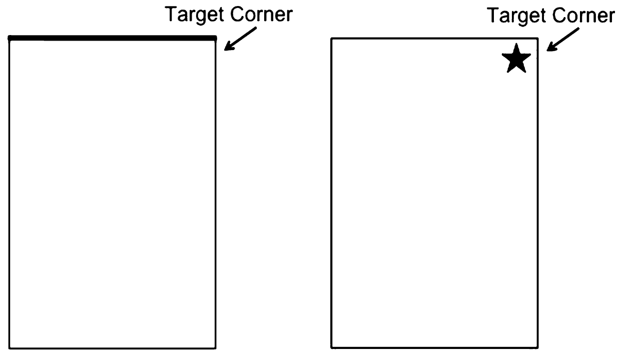

Figure 3 *The target corner in a rectangular space as specified by landmark information such as a different-colored wall (darker side of rectangle, left) or a beacon (black star, right).*

Experiment 2A

To probe further how beacon information may affect the representation of geometry, we examined children's search responses following disorientation when a beacon predicted one location and geometry predicted others. Research with nonhuman animals suggests that rats (Wall *et al*., 2004), pigeons (Kelly *et al*., 1998), domestic chicks (Chiandetti *et al*., 2007; Vallortigara, Feruglio & Sovrano, 2005), and fish (Brown, Spetch & Hurd, 2007) all continue to rely on geometry when non-geometric information such as a beacon or landmark is pitted against it. But only male animals have been tested in these experiments. Experiment 2A was designed to investigate how human children handle conflicting location information and whether there are accompanying sex-related differences.

Method

Participants

Thirty-two children (16 girls) between 18 and 24 months (girls: M = 21.2, SD = 2.1; boys: M = 20.4, SD = 1.9) participated. Four additional children were excluded for failing to keep their eyes covered during disorientation or because of parental interference. Children were given a small gift for participating, and experimental procedures met ethical guidelines.

Materials and procedure

All materials and procedural aspects of this experiment were identical to Experiment 1, except for Phase 2, which here involved a conflict between beacon (distinctive container) and geometry. As the child was being disoriented (i.e. spun around with eyes covered) by his or her parent, the experimenter moved the beacon to a

[2] Results did not differ across trials during Phase 2 ($ps > .1$).

geometrically incongruent corner. For example, if the beacon was at a corner with the shorter wall to the left of the longer wall during Phase 1, it was then placed at one of the corners with the shorter wall to the right of the longer wall for Phase 2 (corner counterbalanced across children). Children, were given one trial in Phase 2.

Results and discussion

Responses were scored as correct if search occurred at the target corner (i.e. the corner with the distinctive container). Preliminary analyses revealed no significant effects of age (ps > .1) or counterbalanced corner (ps > .7) for either phase; thus, these variables were excluded from subsequent analyses.

Phase 1

As in Experiment 1, children of both sexes searched at the target corner significantly above chance [girls: $t(15) = 13.40$; boys: $t(15) = 8.69$; $p\text{s} < .0001$] and significantly more often than the geometrically equivalent corner [girls: $t(15) = 12.18$; boys: $t(15) = 7.15$; $p\text{s} < .0001$; Figure 2, middle]. Additional analyses revealed sex differences in children's use of the beacon and geometry, replicating the results above. Again, girls searched at the target corner more than did boys [$F(1, 30) = 5.10$, $p < .05$, $d = 0.79$; Figure 2, middle]. And, again, when not searching at the target corner, boys went to the geometric equivalent more than chance (11/19 trials, $p < .01$, binomial test, one-tailed), but girls did not (4/9 trials, $p > .3$). Boys made more errors, as in Experiment 1, which they directed at the geometrically equivalent corner.

Phase 2

There was no significant effect of sex in Phase 2, $F(1, 30) = .64$, $p > .4$. Both girls and boys searched at the corner marked by the beacon significantly above chance (girls: 13/16 trials; boys: 11/16 trials; $p\text{s} < .001$; binomial tests), suggesting that children of both sexes favored a beacon over geometry when the two provided conflicting location information.

While similar studies with nonhuman animals point to continued reliance on geometry during conflict conditions, their search responses may depend, to some extent, on training procedures with specific beacons as well as the size of training and test spaces (Chiandetti *et al.*, 2007; Kelly *et al.*, 1998; Vallortigara *et al.*, 2005). Similarly, the specific beacon used in the current experiment may have affected children's responses. We used a distinctive container, with the desired toy placed *inside* it. Even infants understand containment properties; for example, that moving a container does not alter the relation between it and its possessions (e.g. Hespos & Baillargeon, 2001). Thus, it is possible that the 18- to 24-month-olds in this study searched at the distinctive container on the conflict trial because they believed (correctly) that the hidden object moved with the container, not because they favored beacon information over geometry when specifying location. We followed up on this possibility in the next experiment.

Experiment 2B

The beacon here was a flag attached to the outside of a container. Unlike the distinctive container above, this beacon did not directly house the hidden object, such that moving the flag to a different corner did not de facto equal movement of the hidden object. If children continued to favor beacon information on the conflict trial, it would show that their search behaviors were not driven exclusively by the physical properties of the beacon. Further, it would allow us to generalize the findings above to a more ecologically valid beacon. We again asked how young children handle discrepant location information and whether there are sex differences related to the representation of geometry.

Method

Participants

Thirty-two children (16 girls) between 18 and 24 months (girls: $M = 20.5$, $SD = 1.5$; boys: $M = 20.3$, $SD = 1.6$) participated. Three additional children were excluded for failing to cover their eyes during disorientation or because of parental interference. Children were given a small gift for participating, and experimental procedures met ethical guidelines.

Materials and procedure

The flag was identical in color and pattern to the distinctive container used above, even including a happy face (as in Figure 1). Attached to one of the containers, the flag stood 22 cm from the top of the container. The containers themselves (including the one with the flag) were identical to each other (all white, no pattern; see dimensions above). As in Experiment 2A, the beacon remained at the same corner (counterbalanced across children) during Phase 1, and moved to one of the geometrically incongruent corners (counterbalanced across children) during Phase 2. Children were given six trials during Phase 1 and one trial during Phase 2. All other aspects of the procedure were identical to Experiment 2A.

Results and discussion

Responses were scored as correct if search occurred at the target corner (i.e. the corner with the beacon). Preliminary analyses revealed no significant effects of age (ps > .5) or counterbalanced corner (ps > .7) for either phase; thus, these variables were excluded from subsequent analyses.

Phase 1

As in the experiments above, analyses of Phase 1 revealed that children of both sexes searched at the target corner significantly above chance [girls: $t(15) = 9.07$; boys: $t(15) = 3.14$; ps < .01], and significantly more often than the geometrically equivalent corner [girls: $t(15) = 7.33$; boys: $t(15) = 2.38$; ps < .05; Figure 2, bottom]. Also, as above, girls searched at the target corner more than boys [$F(1, 30) = 4.49$, $p < .05$, $d = 0.75$; Figure 2, bottom], and when not searching at the target corner, only boys went to the geometric equivalent above chance (24/51 trials, $p < .05$, binomial test, one-tailed; girls: 15/38 trials, $p > .2$). Notably, though, whereas every girl searched at the target corner above chance, several boys (5/16) did not. To examine whether the greater number of errors by boys was due to their relying exclusively on geometry, we analyzed errors for only those boys who went to the target corner at above chance levels; on 30 error trials, 17 involved responses to the geometric equivalent ($p < .05$). Thus, even boys who clearly encoded the beacon were still more likely to err by searching at the geometrically equivalent corner. These findings extend the sex differences reported above to a beacon that differs in object properties and that more closely resembles non-geometric information typically used in the real world.

Phase 2

Analyses of Phase 2 revealed that children of both sexes tended to search at the corner with the beacon (girls: 8/16 trials, $p < .05$; boys: 7/16 trials, $p = .08$; binomial tests, one-tailed), as was the case with the distinctive container. Thus, even though the flag itself did not contain the hidden object, girls and boys still privileged beacon information over geometry when the two were placed in conflict. One reason for this may be that experience with the initial phase of the task highlighted differences in reliability (Cheng *et al.*, 2007; Kelly & Bischof, 2008). The rectangular space specifies two (equally possible) corners, leaving uncertainty about the target location and reducing the probability of accurate localization. By contrast, there is no uncertainty with a beacon, which unambiguously specifies the target location and likely ensures that it is favored in the subsequent phase, at least with only one conflict trial (cf. Shettleworth & Sutton, 2005).

Another possibility, however, is that the beacons in our experiments were not actually used for location purposes. Perhaps boys and girls went to the corner with the flag or distinctive container because each was more interesting (or attractive) than the other corners (which always contained plain white containers). While we cannot definitively rule out this possibility, it seems unlikely that search had nothing to do with specifying the target location. Children were clearly motivated to find the toy (hidden inside a container), showing visible excitement when they retrieved it and often wanting to help the experimenter hide it. If children were simply interested in the beacons as objects themselves, rather than as sources of location information, one would have expected little motivation to interact with the actual toy. Nevertheless, children may have favored beacons over geometry because of a combination of factors, including greater predictive value and motivational or affective valence (Newcombe & Ratliff, 2007).

Additional analyses of Phase 2 revealed that when children did not search at the beacon, boys were more likely to go to the geometrically congruent corners than the geometrically incongruent corner [$t(15) = 1.78$, $p < .05$, one-tailed], whereas girls showed no preference ($p > .9$). This result suggests further that boys weight geometry more heavily than girls in the presence of a beacon, showing some reliance on geometry in the face of conflicting beacon information, as has been found with male nonhuman animals.

Search times during conflict conditions (Experiments 2A and 2B)

Unlike boys in the experiments above, girls showed no evidence of having encoded geometry, either in their errors during the initial phase of the task or their search choices following two types of transformation. One possibility is that a beacon completely overshadowed geometry for girls (cf. Gray, Bloomfield, Ferre, Spetch & Sturdy, 2005; Pavlov, 1927), such that they simply failed to encode the rectangular space in its presence. An alternative possibility is that girls (like boys) *did* encode geometry, but they gave geometry relatively low weight when representing it in combination with a beacon. Girls' weighting of geometry may have been sufficiently low to support active search choices following disorientation.

To distinguish these possibilities, we compared children's search times in Experiments 2A and 2B during Phase 1 (Experiment 2A: four trials; Experiment 2B: six trials) and Phase 2 (one trial in each experiment). If geometry is encoded during Phase 1, then children should detect the conflict between beacon and geometry during Phase 2, and, consequently, their search times might vary across these phases. As in violation-of-expectation paradigms, we predicted that detecting the conflict would result in an increase in search times, since the mismatch between present and previous contexts would be unexpected. However, if geometry is not encoded during Phase 1, then the conflict ought to go undetected, and search times should not increase in Phase 2.

On each trial, search time was defined as the total time taken by children to select one of the containers (after being disoriented) minus the time spent engaging in non-search behaviors such as interacting with parents, tantrums, and so on. For each child, two coders calculated search times from videotapes. On each trial, discrepancies between coders within 2 s were averaged; those greater than 2 s were discussed and corrected. Except for one girl (Experiment 2A), data from all children (Experiment 2A: 15 girls and 16 boys; Experiment 2B: 16 girls and 16 boys) were available for coding.

ANOVAs conducted on children's search times (trial number and sex as within- and between-subject variables, respectively) revealed significant main effects of trial number [Experiment 2A: $F(4, 116) = 6.16$; Experiment 2B: $F(6, 180) = 9.99$; $ps < .01$], but no other statistically significant effects ($ps > .2$). Follow-up analyses showed that search times decreased during Phase 1 (first half vs. last half) for boys [Experiment 2A: $t(15) = 3.79$; Experiment 2B: $t(15) = 2.52$; $ps < .05$] and girls [Experiment 2A: $t(14) = 3.00$; Experiment 2B: $t(15) = 3.10$; $ps < .05$; Figure 4], suggesting that children of both sexes became more efficient at searching for the hidden object. In contrast, search times increased during Phase 2 (compared to the last half of Phase 1) for boys [Experiment 2A: $t(15) = 2.92$; Experiment 2B: $t(15) = 3.45$; $ps < .05$] and girls [Experiment 2A: $t(14) = 2.51$; Experiment 2B: $t(15) = 2.28$; $ps < .05$; Figure 4], suggesting that children of both sexes detected the conflict between beacon and geometry. Had geometry not been encoded in the initial phase, the conflict would have gone undetected in the subsequent phase and search times would not have increased. That there was no sex difference argues against beacon information completely overshadowing geometry in girls. Instead, it suggests that girls (like boys) represented geometry in combination with a beacon, but, as suggested above, their relatively low weighting of geometry may have been insufficient to support search for the target location.

Could the increase in search times reflect factors unrelated to location representation? One possibility is that children simply became frustrated (or bored) as the task went on, with boys and girls taking longer to search for the hidden object. This possibility, however, is unlikely for two reasons. First, search times did not steadily increase across trials; instead, they decreased during Phase 1. Second, the number of trials during Phase 1 of Experiment 2B (six trials) was greater than the total number of trials for both phases in Experiment 2A (five trials), and, yet, search times decreased over the six trials in Experiment 2B but increased on the fifth trial in Experiment 2A. Another possibility is that auditory cues, potentially available during the beacon's movement to a different corner, led to longer search times because children may have attempted to identify the source of such cues. This possibility is ruled out below.

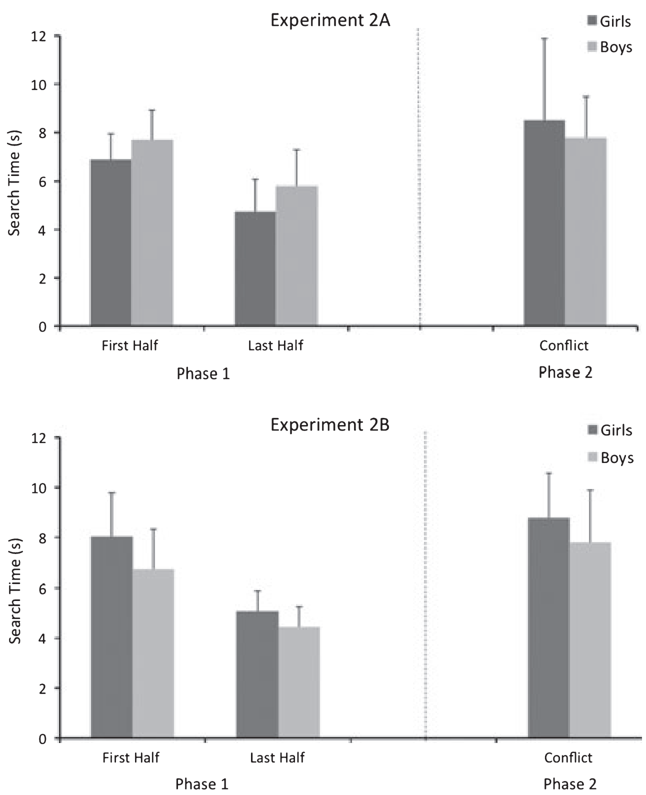

Figure 4 *Mean search times (and standard deviations) in seconds during Phases 1 and 2 of Experiments 2A (top) and 2B (bottom). Search times are presented as a function of sex for the first and last half of trials in Phase 1, as well as for the conflict trial in Phase 2.*

Experiment 3

In this final experiment, we addressed two alternative explanations for the findings above. One of these explanations concerns the finding that during the initial phase of the task girls searched at the corner marked by a beacon more than boys (Phase 1 of Experiments 1, 2A, and 2B). Above we suggested that this might be the by-product of boys placing greater weight on geometry compared to girls. Alternatively, our beacons may have been more girl-friendly, and, consequently, more interesting to girls than boys (Alexander, Wilcox & Woods, 2009; Maccoby & Jacklin, 1974). We addressed this possibility by testing whether the same sex difference is observed in a square space where geometry is inconsequential. If greater search at the target corner reflects greater interest in the beacons themselves, then the sex difference observed above in a rectangular space should generalize to other spaces, even one in which the shape provides no basis for localization.

The other finding concerned boys' and girls' search times in the conflict conditions (Phase 2 of Experiments 2A and 2B). Above we suggested that although boys rely more heavily on geometry than girls, children of both sexes encode geometry in the presence of beacon information, as indicated by the increase in search times when beacon and geometry conflicted. Alternatively, search times could have increased because of auditory cues associated with moving the beacon to a different corner. We tested this possibility by examining search times when geometry was uninformative (square space) and thus never conflicted with beacon information. If longer searching in a rectangular space is the result of children's sensitivity to acoustical differences, then their search times should similarly increase in a space where the target location cannot be specified by geometry.

As in the experiments above, a beacon directly marked the location of an object hidden at one of the corners of the space. However, unlike those experiments, none of the space's corners could be distinguished geometrically. The format of the task was identical to that of Experiments 2A and 2B – a beacon remained in the same corner for multiple trials (Phase 1) and was then moved to a different corner for one trial (Phase 2).

Method

Participants

Thirty-two children (16 girls) between 18 and 24 months (girls: $M = 21.3$, $SD = 1.8$; boys: $M = 20.8$, $SD = 1.6$) participated. Three additional children were excluded for failing to keep their eyes covered during disorientation. Children were given a small gift for participating, and experimental procedures met ethical guidelines.

Materials and procedure

Children were tested inside a square space (wall length: 106.7 cm, height: 45 cm), positioned at the center of a large (opaque) circular enclosure (diameter: 2.9 m; height: 2.4 m). To facilitate comparisons with the experiments above, the beacon was either a distinctive container or flag; 16 children (eight girls) in each condition. As in Experiments 2A and 2B, the beacon remained at the same corner (counterbalanced across children) during Phase 1 (six trials) and was moved to a different corner (counterbalanced across children) in Phase 2 (one trial). All other aspects of the procedure were identical to Experiments 2A and 2B.

Results

Preliminary analyses revealed no significant effects of age on accuracy (i.e. search at the target corner; $ps > .3$) or on search times ($ps > .5$) for either phase. There were also no significant effects of counterbalanced corner on accuracy ($ps > .6$) or search times ($ps > .3$). Thus, these variables were excluded from subsequent analyses.

Accuracy scores

An ANOVA conducted on accuracy scores during Phase 1, with beacon type (distinctive container or flag) and sex as between-subjects variables, revealed a significant main effect of beacon, $F(1, 28) = 20.54$, $p < .0001$, but no other statistically significant effects ($ps > .6$). Children of both sexes searched at the target corner more often when it was marked by the distinctive container than the flag (Figure 5), though performance was significantly above chance with both beacons ($ps < .01$) for boys and girls (who did not significantly differ). Children's responses during Phase 2 similarly revealed no effects of sex for either beacon ($ps > .5$), with boys (distinctive container: 6/8 trials; flag: 5/8 trials, $ps < .05$; binomial tests, one-tailed) and girls (distinctive container: 7/8 trials, $p < .0001$; flag: 4/8 trials, $p = .1$; binomial tests, one-tailed) tending to search most often at the corner marked by a beacon.

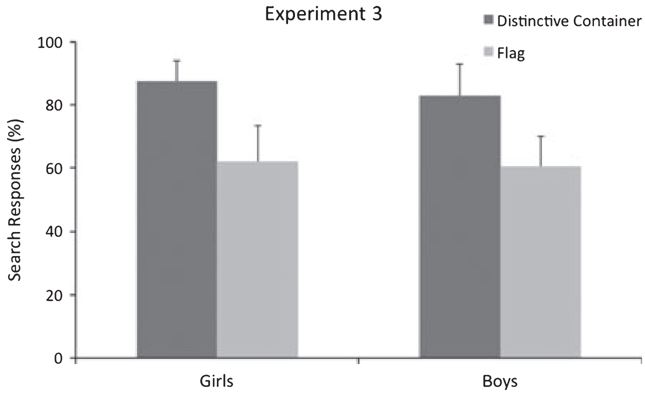

Figure 5 *Mean percentage (and standard deviation) of search responses at the target corner for the different beacon groups (distinctive container and flag) during Phase 1 of Experiment 3. Search responses are presented separately for girls and boys in both groups.*

Search times

ANOVAs conducted on search times (trial number and sex as within- and between-subjects variables, respectively) revealed a significant main effect of trial number [distinctive container: $F(6, 84) = 9.07$; flag: $F(6, 84) = 7.33$; $ps < .0001$], but no other statistically significant effects ($ps > .1$). Follow-up analyses showed that search times decreased during Phase 1 [distinctive container: $t(15) = 4.57$; flag: $t(15) = 3.78$; $ps < .01$] and into Phase 2 [distinctive container: $t(15) = 2.26$, $p < .05$; flag: $t(15) = 1.77$, $p = .097$; Figure 6].

Discussion

We found that boys and girls searched equally often at the corner marked by a beacon. That there was no sex difference in a square space suggests that girls were not more interested than boys in the beacons. It also supports the explanation above – that geometry interferes with the use of beacon information, at least in boys. We also found that search times did not increase following the beacon's movement to a different corner. Instead, there was a steady decrease across trials, suggesting that Phase 2 was treated like Phase 1 in a square space, and supporting the explanation that longer search times in a rectangular space reflect detection of conflicting location information rather than auditory cues. Because we used

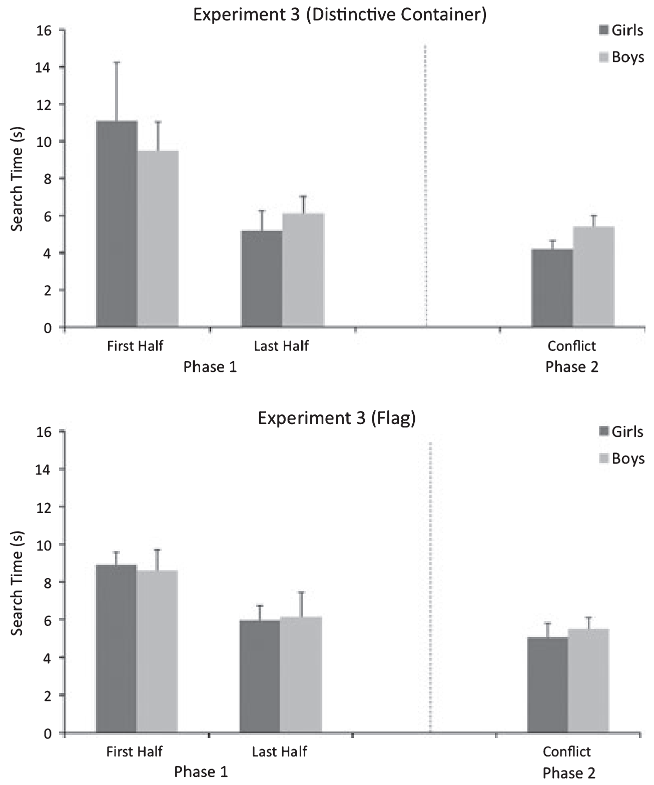

Figure 6 *Mean search times (and standard deviations) in seconds during Phases 1 and 2 of distinctive container (top) and flag (bottom) groups in Experiment 3. Search times are presented as a function of sex for the first and last half of trials in Phase 1, as well as for the conflict trial in Phase 2.*

the same beacons and procedures as in Experiments 2A and 2B, it is unlikely that acoustical differences detectable in those experiments went unnoticed here.

Although we found no sex difference in children's use of beacon information and no increase in search times following movement of a beacon, accuracy clearly varied by beacon type, suggesting that despite similarities in surface features, the beacons were treated differently by children. While the distinctive container and flag are equal in predictive value, they vary in the degree of spatial contiguity to the hidden object, and even subtle contiguity differences are known to affect how beacon information is used to solve location problems (Bremner, 1978; Chamizo, Rodrigo, Peris & Grau, 2006). In our task, the distinctive container housed the hidden object, such that beacon (distinctive container) and toy (hidden object) may not have been fully dissociable, perhaps even considered one and the same by children. By contrast, the flag was at least one step removed from the toy, which may have made encoding and subsequent use more demanding.

General discussion

Despite great interest in how humans represent location information, the nature and developmental origins of accompanying sex differences remain poorly understood. Do sex differences in the use of geometric cues reflect differential processing abilities or subtle variation in problem-solving approach? When do sex differences in location representation emerge over development and what are the mechanisms that support these differences? To begin to shed light on these questions, we examined how young boys and girls treated geometry (rectangular space) when a beacon (distinctive container or flag) was also available for specifying location.

Our findings revealed two clear sex differences by 18 to 24 months of age, both of which, as suggested above and discussed more thoroughly below, may be rooted in the differential weighting of geometry when geometry is represented in combination with a beacon. One of the sex differences concerned children's use of beacon information when searching for a hidden object. When geometry provided additional (non-conflicting) information, girls searched at the target corner consistently more often than boys (Phase 1: Experiments 1, 2A, and 2B). Importantly, however, there was no such sex difference when beacon and geometry were placed in conflict (Phase 2: Experiments 2A and 2B); nor when geometry was irrelevant (square space: Experiment 3). The other sex difference in our experiments concerned children's use of geometry for specifying the target location. In a rectangular space, boys, but not girls, were more likely to err during the initial phase of the task by searching at the geometrically equivalent corner (Phase 1: Experiments 1, 2A, and 2B). In subsequent phases, only boys searched at the geometrically appropriate corners when beacon information was no longer available (Phase 2: Experiment 1) and only boys showed some evidence of relying on geometry when one of the beacons (flag) conflicted with geometry (Phase 2: Experiment 2B). Taken together, these findings suggest that boys place greater weight on geometry than girls, and this weighting may affect children's use of both beacon information and geometry when searching for a hidden object following disorientation.

How do boys and girls weight geometry?

To prevent children from solving the location problem via an egocentric strategy, we included a disorientation procedure in our task. Using this procedure, other studies (noted above) have shown that boys and girls are equally capable of using geometry to guide search, either when only the shape of the space predicts the target location, or when landmark information, rather than a beacon, is also available. Although girls' search choices appear to have been uninfluenced by geometry, analyses of children's search times in the conflict conditions (Experiments 2A and 2B) are consistent with girls having in fact encoded geometry. We would thus propose that the sex difference in geometric weighting, rather than reflecting early differences in the ability to process geometry, reflects subtle variation in how boys and girls approach the problem of combining multiple sources of location information.

A major component of solving any location problem is determining how to represent the relevant environmental cues. When multiple cues are available for use, this may entail selecting among them and encoding only a subset. It may also involve weighting the encoded cues in terms of their relevance to specific location problems and spatial tasks more generally. These decisions, which often occur automatically and without conscious awareness (Huttenlocher & Lourenco, 2007), may be based on various factors such as computational demands, predictive value, and salience (Cheng *et al*., 2007; Newcombe & Ratliff, 2007). Our findings suggest that children of both sexes favored beacon information over geometry, which above we accounted for in terms of reliability and motivational or affective valence. When combining beacon information with geometry, however, boys and girls appear to vary in their weighting of geometry, similar to that reported in adults (e.g. Kelly & Bischof, 2005; Sandstrom *et al*., 1998). The lower weighting of geometry by girls, although clearly sufficient to permit detection of a discrepancy between beacon information and geometry, may have been insufficient to support active search.

The sex difference in geometric weighting may explain why, when beacon and geometry were both available during the initial phase of the task, boys were less likely than girls to search at the target corner, making more errors in locating the hidden object. By relying more heavily on geometry, boys may have experienced interference from the surrounding rectangular space. Such interference effects may have been minimized when beacon and geometry provided conflicting location information (Phase 2: Experiments 2A and 2B) and altogether absent in a square space (Experiment 3). While interference from simple geometry such as a rectangular space may prove especially difficult for young children, it is likely overcome in older children and adults, perhaps accounting for why men and women rely on non-geometric information at comparable levels (e.g. Chai & Jacobs, 2010).

Also using a disorientation task with multiple phases, Wall and colleagues (2004) found that male rats favored beacon information, while, simultaneously, continuing to rely on the geometry of a surrounding (rectangular) space to specify the target location. Indeed, when the beacon was made uninformative, rats searched at the geometrically appropriate corners, much like the boys in our study. Such findings have been taken as evidence for the privileged status of geometry. Yet female animals have generally not been included in studies examining the use of geometry following disorientation. Given our findings with human children, future research with nonhuman animals would do well to examine how males *and* females represent geometry when various types of non-geometric information (i.e. beacons or landmarks) are also available for specifying location (for a similar proposal, see Jacobs & Schenk, 2003).

Given that beacon information is perfectly predictive of the target location, at least during the initial phase of these tasks, why encode geometry at all? Giving geometry any weight could be considered non-optimal, since it adds nothing to localization. Yet its combination with a beacon might lead to greater accuracy over the long term, especially if beacon information proves unstable (Gallistel, 1990). Indeed, while children and nonhuman animals generally prefer a beacon for location purposes, geometry appears to continue to operate in the background. The obligatory encoding of geometry may function as an adaptive backup system. If non-geometric information fails to deliver, then geometry can be used in its place. Of course, this interplay likely depends on the predictive value associated with geometry. Future research might examine how the integration of geometric and non-geometric information is affected by enclosed spaces in which the geometry yields greater precision of localization than a rectangular space.

Rather than differential weighting of geometry by boys and girls, an alternative account of the current findings might emphasize sex differences in the time course of learning. Research in adults examining training effects on mental rotation performance points to sex differences in learning trajectory, with women showing more gradual improvements than men (Terlecki *et al*., 2008). Similarly, girls and boys in our study may have varied in the rate at which they learned to integrate geometry with a beacon. On this account, children of both sexes would place equal weighting on geometry, but differ in their learning to combine location information. Future research might consider distinguishing between weighting and learning accounts, perhaps by varying the number of trials given to children or by comparing performance with enclosed spaces that vary in geometric complexity.

A caveat of the current study is that our task took place inside a relatively small space, and space size is known to affect location representation (e.g. Learmonth, Nadel & Newcombe, 2002). Small and large spaces differ in the costs associated with making errors. In a smaller space, errors in localization are not particularly costly; searching at another corner can be accomplished relatively quickly and with little effort. The task demands, however, may be quite different in larger spaces, where walls could be considerably longer and the corners farther apart. While this could translate to even greater reliance on beacon information (provided it remains unaltered), it could, alternatively, lead to greater weighting of geometry, which if the beacon became uninformative would result in fewer errors.

Potential explanatory mechanisms of sex differences

Why might boys and girls vary in their approach to solving a location problem, specifically in their weighting of geometry? Research with nonhuman animals is suggestive of biological mechanisms. In rats, Williams, Barnett and Meck (1990) found that neonatal exposure to estradiol benzoate (a metabolite of testosterone) resulted in greater weighting of geometry (rectangular space) relative to landmark information (see also Rodríguez, Torres, Mackintosh & Chamizo, 2010). Studies with humans point to a complex relation between spatial cognition and exposure to testosterone (Liben, Susman, Finkelstein, Chinchilli, Kunselman, Schwab, Dubas, Demers, Lookingbill, Darcangelo, Krogh & Kulin, 2002; Moffat & Hampson, 1996; Resnick, Berenbaum, Gottesman & Bouchard, 1986). It is well documented that hormones operate differentially over development, with both organizational and activational effects. Testosterone levels peak early in human life (prenatally and after birth until approximately 5 months) and then again at puberty (e.g. Hier & Crowley, 1982), suggesting that if exposure to testosterone affects location representation in children, it likely does so via prenatal or early postnatal organization of associated neural regions.

It is not uncommon for researchers to argue that early developing sex differences are more consistent with biological constraints than environmental influences. Even the earliest sex differences, though, could be the result of specific postnatal experiences, or more likely still, some combination of biology and experience (e.g. Ruble, Martin & Berenbaum, 2006). In humans, it has been suggested that toy preferences and differential exposure to activities such as block construction and puzzles contribute to the development of sex differences in spatial cognition (Alexander, 2006; Newcombe, Bandura & Taylor, 1983). But why might boys and girls differ in such experiences? One possibility is that caregivers and teachers encourage gender-typed play from early in life (Caldera, Huston & O'Brien, 1989; Lytton & Romney, 1991). Another possibility is that biological predispositions constrain children's experiences. For example, the relation between testosterone and location representation could be indirect and mediated by hormonal effects on activity preferences. Prenatal hormones have been linked to sex-related interests such as toy preferences (Berenbaum & Hines, 1992; Wallen, 2005).

While direct evidence is lacking, it is possible that differential engagement with particular objects and mechanical-type activities early in development (Carter & Levy, 1988; Liss, 1981) may serve to highlight spatial relations both internal and external among simple objects and complex arrays. Such experiences could make particular individuals more attuned to geometric cues such as distance/length, direction/sense, and the overall shapes of spaces. It is also possible that early sex differences in experience may serve to sustain (or exaggerate) biological predispositions, leading to at least some of the differences observed later in life between men and women on location tasks. In future research, it will be critical to examine questions concerned with developmental continuity and change, so as to determine more precisely how spatially related sex differences in young children relate to those observed in older children and adults.

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