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Two-year-old children interpret abstract, purely geometric maps

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Abstract

In two experiments, 2.5-year-old children spontaneously used geometric information from 2D maps to locate objects in a 3D surface layout, without instruction or feedback. Children related maps to their corresponding layouts even though the maps differed from the layouts in size, mobility, orientation, dimensionality, and perspective, and even when they did not depict the target objects directly. Early in development, therefore, children are capable of noting the referential function of strikingly abstract visual representations.

One of the defining attributes of human intelligence is our ability to make and use symbols: they allow humans to acquire knowledge far beyond our direct experience, and give voice to thoughts that would otherwise remain confined within us. Yet the nature of human intuitions about symbols remains unclear. The widespread presence of symbols across cultures suggests that our species is uniquely predisposed to use them, but the literature on symbolic development implies a large role for learning and cultural transmission in the emergence of symbols (see DeLoache, 2004).

Here we consider the case of metric maps: visual representations that preserve the relative distance and absolute angle and sense (left/right) relations in an overhead projection of their referent entities[1]. Because they highlight spatial relationships in part by abstracting away from the usual viewpoint and appearance of a thing or place, metric maps offer a particularly strong test of human intuitions about symbols. We ask: can young children, who likely have little experience using abstract depictions, derive spatial information from such a map? Or is the ability to decipher spatial symbols constructed only through years of formal schooling?

Maps and children's spatial understanding

Many experiments report a relatively late emergence of geometric map reading abilities in children. In several studies, three-year-old children could use a map to locate objects in a

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[1]Note that not all maps are metric in this sense: our research does not speak to children's developing sensitivity to maps of lower fidelity (e.g., topological maps).

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room, but only when the map was aligned with the room, allowing for performance based on visual matching or motor priming (Blades and Cooke, 1994; Bluestein and Acredolo, 1979), or when each form on the map was visually similar to its referent and therefore served as a local cue to the target location (e.g., Blaut, McLeary & Blaut, 1970; Marzolf & DeLoache, 1994; Dow & Pick, 1992). In one study, preschool children had difficulty using a map of their classroom when the target locations could be individuated only by spatial information, as opposed to other identifying traits (Liben & Yekel, 1996). Similarly, 5- and 8-year-old children, presented with maps that were rotated relative the room, appeared primarily to code target locations as near or far from a single distinctive landmark, but not in terms of their relative distance and angle relations with a set of other locations (Presson, 1982).

Several recent studies nevertheless suggest that children can detect geometric information in maps if they are not hindered by the presence of distinctive landmarks. In one study, 4- and 5-year-old children were presented with a map task in which target locations were distinguished by their positions relative to one another but not by their positions relative to the child (Shusterman, Lee & Spelke, 2008). Under these conditions, chldren performed *better* when landmarks were absent (i.e., all target locations were marked by indistinguishable objects in the room and identical markings on the map) than when they were present (i.e., when one target location, and marking on the map, differed in shape and color from the others). Indeed, children as young as 3 years, presented with a map and an array devoid of distinctive landmarks, demonstrated use of distance (Huttenlocher, Newcombe & Vasilyeva, 1999) or angle (Vasilyeva & Bowers, 2006) after a brief training and with corrective feedback. Prior research therefore may have underestimated young children's map reading abilities by emphasizing visual over spatial cues.

Two further lines of research give reason to take this possibility seriously. First, sensitivity to the geometric structure of both visual patterns and spatial arrays begins to develop in infancy. Infants can track the corners of an isosceles triangle under rotation (Lourenco & Huttenlocher, 2008) and notice changes in the shapes and symmetries in figures (e.g., square vs. rectangle) over variations in orientation (Schwartz & Day, 1979). Toddlers are sensitive to the geometric layout of a familiar room (Lew et al., 2005), and they reorient by distance and sense cues in rectangular (Hermer & Spelke, 1994; 1996), triangular (Huttenlocher & Vasilyeva, 2003), and more complexly shaped (Wang, Hermer & Spelke, 1999; Hupbach & Nadel, 2005; Bullens et al., 2010; Lee & Spelke, 2010; Lee, Sovrano & Spelke, 2012; Newcombe, Ratliff, Shallcross & Twyman, 2009) environments (but see Lew et al., 2010, and Lee, Sovrano & Spelke, 2012, for evidence of difficulty with fragmented arrays that differ in symmetry or angle). The sensitivity to geometry that underlies mature map reading, then, may be available for navigation from the start. Of course, these data do not speak to the question of whether very young preschoolers would understand the symbolic function of metric maps.

The second source of evidence lending credence to early map-reading abilities comes from studies of people likely to have had little experience with spatial symbols. Landau (1986) reported on the sophisticated mapping abilities of a 4-year-old child blind from birth who had never encountered spatial symbols prior to testing. And child and adult members of a remote Amazonian tribe, who likely encountered paper maps for the first time at testing,

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performed well above chance on several map tasks (Dehaene et al., 2006). Together, these studies raise the possibility that sensitivity to geometry in maps might be present early in symbolic development.

Maps and children's symbolic understanding

Even if children's early geometric understanding were sufficient to discern the spatial information in maps, however, it is not clear when children's *symbolic* understanding is mature enough to discern the representational nature of a map. Paradoxically, the very factors that encourage children's use of geometry in maps—the presentation of maps that lack any recognizable landmarks—might hinder children's ability to view the map as a representation of a navigable spatial layout. In addition to abstracting away from an embedded view of space to a birds-eye view, purely geometric maps convey little information about the appearance of the locations or entities they represent. Children also rarely encounter such representations, in contrast to the pictures that are ubiquitous in children's environments.

Several studies suggest that iconicity (i.e., visual similarity between a symbol and its referent) may foster children's understanding of visual symbols. Symbolic media surround Western children essentially from birth, and the ability to perceive the similarity between pictures and the objects they depict appears even in the absence of this experience (e.g., Hochberg & Brooks, 1962). By 18 months children generalize the name for an iconic drawing or photograph to its real-world referent (Preissler & Carey, 2004), although this ability is quite fragile—it depends on a high degree of similarity between the image and referent (Ganea, Allen, Butler, Carey & DeLoache, 2009). The understanding that pictures can refer to larger scenes, moreover, appears to emerge only between 24 and 30 months of age, as evidenced by children's use of a photograph as a cue to the location of a hidden object in a picture-based retrieval game (DeLoache, 1987; 1991; DeLoache & Burns, 1996; DeLoache & Marzolf, 1994; Dow & Pick, 1992, but see DeLoache & Burns, 1994; Suddendorf, 2003). In all these studies, however, the pictures were highly iconic of their referents in the scene, raising the possibility that young children may not be able to discern the representational nature of an abstract map, whose symbols do not clearly resemble their referents.

Two recent studies further suggest that even at 30 months, children's pictorial understanding may depend not only on iconic cues, but also on the scaffolding of language (Callaghan, 1999; 2000). In one study, children failed to use abstract line drawings of novel objects as a cue to which object to give to an experimenter when none of the objects in this study were named (Callaghan, 1999). Moreover, when children were shown a picture of a familiar entity (e.g., a tiger) and asked to choose the corresponding object, they succeeded when they knew a basic-level kind term for the depicted entity that distinguished it from the foil (e.g., cat vs. dog) but not when they did not (e.g., tiger vs. cheetah). These studies raise the possibility that iconicity provides a basis for identifying the names for the referents of a picture (see Travis et al., 2011), and that internally generated names may underlie young children's understanding of visual symbols. If this is the case, then 2-year-old children might not be

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able to derive spatial information from maps, if it is not encoded linguistically. The present studies test this suggestion as well.

Summary

We have reviewed evidence that from infancy, the faculty for reasoning about space may be developed enough to allow for interpreting the spatial information in maps. Although the evidence on children's map-reading abilities is mixed, it is possible that children perform better on tests that emphasize the spatial nature of maps by removing non-spatial visual details. But abstraction potentially creates another problem for young children, as the literature on symbolic development has no demonstrations of early competence with anything other than highly iconic symbols. The present studies therefore explore both young children's ability to interpret purely geometric symbols, and their ability to grasp the representational nature of non-iconic, namable, symbols.

Overview of the present studies

Two experiments investigate whether children can interpret purely geometric maps at an early point in the development of their understanding of visual symbols. We presented 2.5-year-old children with maps consisting of simple 2D geometric patterns depicting an arrangement of 3 solid objects seen from above. Each map differed from the array it depicted in orientation, size, dimensionality, and perspective, and the map and array were never simultaneously in view. Moreover, because the position of the map relative to the array varied parametrically, children could not use the map as a directional marker, and they could not locate the target by processes of visual matching or motor priming.

Three further features of our method distinguish these studies from prior research. First, the maps provided only geometric cues to reference, because all the objects in the array were identical and were indicated on the maps by three identical markings (in Experiment 1) or by a single triangular outline (in Experiment 2). Second, the relationship between the symbols on the map and the objects in the 3D array was not explicitly pointed out (children were not told, e.g., "this circle is the same as that chair"). The representational function of the pictures was noted *implicitly* by being described as "a picture of the room" and through labeling a marking by the name for its referent (or with anaphora), but children were never told, e.g., "this circle is the same as that chair." Third, children were not given corrective feedback on their choices. All these features contrast with past research on 2-year-old children's use of visual symbols (e.g., DeLoache & Burns, 1994; Marzolf & DeLoache, 1994).

Finally, because the maps 1) are spatially and visually abstract, and 2) contain either identical markings for each referent object (Experiment 1) or no discrete markings for objects whatsoever (Experiment 2)—and cannot be individuated by basic-level kind names—these experiments provide a particularly stringent test of children's symbolic and geometric competence. If children can derive only names (and not locations) from pictures, they would perform at chance in this map task, selecting target objects at random, because the single label given applies equally to target and non-target locations in the room. Likewise, if children are unable to detect the same abstract geometrical property in arrays

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that differ in size, orientation, and dimensionality, then again they should fail this map task. If, however, children appreciate that the geometric properties of visual symbols can convey spatial information, they might be able to use the abstract maps to guide their navigation.

Experiment 1

In Experiment 1, children were asked to place a puppet in or on one of three identical objects (chairs or buckets) after the intended target was indicated on a 2D map of the array. The 3D arrays of objects were organized in one of two configurations: an isosceles triangle or a line (see Figure 1 for examples of maps and the layout of each array). In the line condition, the three object positions were distinguished by their *distance* relations (because the central object was closer to one end than to the other), and the central object also was distinguishable by the relation of *betweenness*. In the triangle array, the object positions were fully specified by their *distance* and *sense* relations (because the three corners were bounded either by two long sides, by a long side on the left, or by a long side on the right), and the apex location was distinguished from the others by *distance* and *angle*.

For each array, children were tested at two of the three possible locations. Each child received a test at the apex of the triangle and at the distant line location (hereafter, the “distant” locations), but at only one of the two base corners and only one of the two close-together locations (hereafter, the “proximate” locations). This design served to limit the total time of the study (which was otherwise long enough to prompt concerns about high rates of attrition during pilot testing), and was motivated by the longstanding evidence that even considerably older children are insensitive to sense relations in distinguishing between the mirror-image corners of an isosceles triangle (see Dehaene et al., 2006; Izard & Spelke, 2009; Lourenco & Huttenlocher, 2008; & Shusterman, Lee & Spelke, 2008; Vasilyeva & Bowers, 2006). This design entails that no location was tested 33% of the time: each distant target was tested 50% of trials and each proximate target on 25% of trials. We discuss the data analysis for this design in the Analyses section below.

In order to ensure that children were attending to the information presented in the map and to check for their memory of that location, each trial began with four location memory checks, where the child pointed to the 2D target on the map itself prior to placing the object in the 3D array. Between each memory check, the map was rotated out of children’s line of sight to a new orientation, in steps of 90 degrees away from the starting orientation. Because each child pointed to the 2D target at 4 different orientations, the memory checks prevented children from using the map as a directional cue (as in, “the one next to mommy”) and encouraged children to encode the 2D targets in terms of their positions relative to one another.

Following the memory checks, children were asked to place the doll on the 3D object that corresponded to the 2D target. We measured children’s correct placement at each location in each array. Thus, Experiment 1 explored whether children would make spontaneous use of any of the geometric properties of relative distance, angle or sense that were constant between the map and the 3D array in guiding their inference of where the doll wanted to sit.

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Because the objects in the test arrays were identical to each other, correct placement can only be achieved through some use of the spatial information on the maps that distinguish among them. In order to increase the salience of the spatial nature of the task, maps were constructed to provide little iconic information about the referents of the symbols. That is, the aerial maps depicted buckets and chairs with flat, monochromatic circles and squares, respectively, not with iconic pictures or line drawings. Further, on the line and triangle test trials, while gross shape and color were available as cues to reference, only spatial information served to identify each target on the map and in the 3D array.

The symbolic nature of the task was conveyed in several ways. Prior to the experiment, all children received two warm-up trials in which a picture cued them to place a toy in one of two distinct objects (a red box and green bowl, represented on a picture by a like-colored square and circle, respectively). Because the objects were clearly distinguishable by shape and color, we reasoned that this task might help children to establish the representational status of the map. These non-spatial warm-up trials also serve as a check on the suitability of the abstract stimuli, since the 2D targets were not pictures of boxes or buckets. Each map was introduced as “a picture of the room” and each symbol was pointed out and labeled (“there’s one chair, there’s the other one…”).

Method

Participants—Twenty children (9 females, age range 28–32 months, M = 29.5 months) participated in the experiment, and three more children failed to finish the study due to fussiness. Participants were contacted from a database of Cambridge-area families that had expressed an interest in participating in research. Although letters were sent to families from ethnically and socially diverse communities, participants were volunteers who responding to the mailing and the children in both studies were largely White and middle-class.

Materials and apparatus—Testing took place in a 3.8 m diameter cylindrical room. On warm-up trials, a green bowl and red box were placed .67 m apart. On triangle test trials, three identical green buckets were placed in an isosceles triangle (height 1.5 m base .75 m). On linear test trials, three identical red chairs were placed in a line at unequal distances (.6 m and 1.2 m). All arrays were centered in the room at a fixed position and orientation (see Figure 1), and consisted of objects ranging in height from approximately 25 to 50 cm. Maps were marked with two or three colored circles (2cm diameter) or squares (2cm across), depending on trial type, all printed on 25cm-diameter circles of white paper. The markings preserved the gross color and shape of their referents, and were scaled to the sizes and positions of their 3D objects by a factor of approximately 12. Two palm-sized felt dolls indicated the map locations and served as the objects on the placement trials.

Design—Test trials were blocked by array type (linear or triangular), with block order counterbalanced across children. Each child received 4 test trials in total. The starting orientation of the map on each trial (0°, 90°, 180°, or 270° relative to the object array) was counterbalanced both within and across children. Within each trial block, children received one test at the “distant” location (the apex of the triangle and the farther end of the line) and one test at a “proximate” location (the base corners of the triangle and nearer two targets in

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the line); these locations are defined pictorially in Fig. 1. The location of the proximate target was counterbalanced across children, and the order of trials within blocks was counterbalanced within and across children. Note that, because the three locations within each array were not tested with equal frequency, this design allows us to assess children's sensitivity to the geometric relations of relative distance/angle, sense (left/right), and betweenness, but not to test against chance at each individual location, as we have no estimate of children's bias towards any single location independent of the map.

Procedure—The objects used on each trial were presented at the start of each trial. After entering the testing room, children were introduced to the dolls, the first (warm-up) 3D object array, and the task by being told that the dolls had a "favorite place to sit in the room" and that the child's job was to help find it. It was explained that rather than tell the child where they wanted to sit, the dolls would show the location using a "picture of the room." The map for warm-up trials was presented in alignment with the array and directly between the children and the array, and each marking was labeled by the name for its referent—the experimenter said, e.g., "there's the bowl and there's the box," and indicated the marking corresponding to the doll's favorite place to sit ("Kermit's favorite is this one here"). Children were then given a location-memory check: they were asked to point to the place that Kermit had indicated, and were corrected if necessary (6 children). Finally, children were asked to place Kermit in his favorite place to sit. On three occasions during the warm-up trials, children initially placed Kermit on the picture itself; these children were told, e.g., "good job, you got Kermit on the picture, but he wants to sit in one of these things here" (gesturing towards the warm-up objects). The script for warm-up and test trials is given in Table 1.

The procedure for the test trials closely mirrored that of training trials, with three important differences. First, prior to presenting the 2D maps, the child was turned to face away from the 3D object array, so that the map and array could not be seen together. Second, instead of aligning the map with the array as in warm-up trials, the map was rotated with respect to the array and appeared at different orientations within a single trial, and four location-memory checks were administered instead of one, one at each of four map orientations. Third, the symbols on the map were referred to (either lexically or with anaphora) by the names of their referents, which may have cued the child that the map was providing information about the 3D array of objects but provided no cue to the correct referent. On each trial, the label was given once and followed by anaphoric reference: "there's one chair, there's the other one, and there's the other one." On all test trials, children spontaneously took the doll from the experimenter and placed it on a 3D object.

Analyses: The experiment was videotaped by an overhead camera. Responses on the location-memory checks were coded by the main experimenter as they occurred, for the maps could not be seen clearly from this video record. The critical data from the object placement trials were coded from the video record by trained observers. A child was judged to have designated a location when the doll was unambiguously placed on or in one of the referent objects.

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Children's use of the map to guide their object placing was assessed by focusing on their sensitivity to the geometric relations of *relative distance/angle* and *sense* in the triangular array, and *relative distance* and *betweenness* in the linear array, as these properties are together sufficient for distinguishing among all targets in each array. Use of distance/angle was defined as children's correct choice of the distant location when it was target and correct avoidance of it when it was not; use of sense was defined as children's ability to distinguish one corner of the triangle from its mirror opposite; and betweenness as children's ability to distinguish the middle target from each end.

Although children's responses would converge on 33% if responding by chance alone (i.e. randomly), children could score better than 33% merely by biasing their responses towards to distant targets, which were tested on 50% of trials. We address this issue in two ways in our analyses. First, we check to see whether there is any evidence of the distance bias that would artificially inflate children's performance relative to chance (and find none). Second, we conduct targeted analyses of children's sensitivity to distance/angle and sense; for these tests, each location is correct on half the trials and incorrect on half the trials, so chance is 50% correct.

Results—Preliminary analyses of variance revealed no effects of gender or order of trial blocks on any dependent measure, so subsequent analyses collapsed over these variables. Across the two warm-up trials, children chose the correct targets 75% of the time (chance = 50%), $t(19) = 3.30$, $p < .01$.[2]

Location-memory checks (pointing to the correct symbol on the map)—Across all pointing trials, children pointed correctly 58% of the time. This is better than what would be expected in children were responding randomly (33% chance), $t(19) = 8.0$, $p < .0001$.[3] For the triangular array, children correctly pointed to the apex on 60% of trials and correctly avoided it when it was not target on 73% of trials, thus reliably pointing to the distance/angle-appropriate target 66% overall, $t(19) = 3.44$, $p < .01$. This suggests sensitivity to the distance/angle information that distinguishes the distant target. When the target was one of the base corners, moreover, children pointed to the correct corner more often than its mirror twin (48% versus 25%), $t(19) = 2.49$, $p = .02$, suggesting sensitivity to the relation *sense* that distinguishes them. For the linear array, when the middle location was target, children pointed to that location (58%) and avoided it when it was not target (pointing to it on only 15% of trials when the proximate end was target, and 6% of trials when the distant end was target). Evidence of children's ability to distinguish the ends by their relative distance to the middle was mixed, however: When the proximate end was target, children were no more likely to choose that location than the distant end (48% vs. 38%), $t(19) = .75$, *ns*. When the distant end was target, meanwhile, children chose it reliably more often than the opposite end (71% vs. 23%), $t(38) = 7.14$, $p < .0001$, but also chose the opposite end more often than the middle, $t(38) = 2.87$, $p < .01$. Across both linear trials, children chose the middle/end-

[2]All significance tests reported here are 2-tailed.

[3]Because a bias to the point to the distant location would inflate artificially performance relative to chance, we checked for evidence of such a bias and found none: a bias would result if children pointed to the distant location on more than the 50% of trials when it was the correct target, but they pointed to the distant location on 50% of linear trials and 44% of triangle trials.

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appropriate target on 83% of trials, which is better than the 58% expected by chance, $t(19) = 7.11$, $p < .0001$. Thus, children were able to encode the 2D map locations by the geometric properties of distance/angle, sense, and possibly betweenness, allowing us to ask whether children were able to use the maps to locate the 3D objects in the room.

Test trials (placing Kermit on the objects in the room)—Children's placing data for Experiment 1 are graphed in Figure 2. Overall, children chose the correct target 49% of the time, which is better than would be expected if children were responding randomly (33%), $t(19)=2.83$, $p=.01$[4]. The following analyses focus on sensitivity to specific geometric relations. We asked first whether children were sensitive to the geometric relation *sense*, defined by their ability to distinguish between the two base corners on triangle trials. When a base location was the target, children were no more likely to choose the correct base location (40%) than the rotationally equivalent corner (50%), binomial $p > .1$, suggesting that children were unable to use the relation *sense* to distinguish among the base targets for placing. However, children correctly chose the apex when it was target 50% of the time and correctly avoided it when a base location was target 90% of the time, suggesting that they were sensitive to the distinction between apex and base. Indeed, children chose the distance/angle-appropriate target on 70% of trials, which is better than the 50% that would be expected by chance, $t(19) = 2.83$, $p = .008$, indicating that children used *relative distance* or *angle* to locate targets. Finally, children were marginally better at avoiding the apex location than at locating it, *McNemar's* χ^2 $(1) = 3.27$, $p = .07$.

On linear trials, children were no more likely to choose the correct end (35%) than the incorrect end (40%) and thus failed to use their relative distance from the middle location to differentiate them. In contrast, children were highly likely to place the doll at the middle location when it was the correct referent (90% correct) and to avoid that location when it was not (75% correct). Pooling across these trials, children chose the middle/end-appropriate referent 83% of the time (chance = 58%[5]), $t(19) = 4.33$, $p < .001$. Thus, they appeared to use the relations "middle" and "end" to individuate the objects in the line, but did not further distinguish among the two ends.

Discussion

Across two arrays of objects, children used maps as cues to where to place an object in the array. Because this task provided no instruction or corrective feedback, gave nothing but spatial cues to match the maps to the 3D arrays, and was likely novel in both materials and procedure, children's performance suggests a spontaneous ability of 2.5-year-old children to relate the geometry of spatial symbols to the world. This result is particularly striking in light of evidence that these children have only recently begun to achieve representational insight into pictorial symbols (e.g., DeLoache & Burns, 1994), and because much older children have been shown to have difficulty deriving spatial information about 3D arrays from maps.

[4]As above, testing against random responding (33%) is licensed only if children are not biased towards the distant locations. They were not: they placed the doll at the distant location on 38% of linear trials and 30% of triangle trials, less than the 50% of trials on which a distant location was the correct target.

[5]Chance for this test is given by weighting the probability of success at each location (2/3 for the ends, 1/3 for the middle) by the frequency of each test: ends were correct on 75% of trials and the middle on 25% of trials.

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Nevertheless, children's performance on the 2D arrays and 3D arrays was far from perfect. Like the 4-year-old children tested in past studies using similar arrays (Shusterman et al., 2008), these younger children failed to use sense information in the map to specify the target object—while they distinguished between the apex and base corners of the isosceles triangle, they treated each same-angle base corner interchangeably. Also, children appeared correctly to avoid the unique triangle target more often than they correctly located it, probably because random responding on some trials will tend to raise performance on the proximal targets (whose chance rates of selection are 67%) relative to the unique target (whose chance rate of selection is 33%). Finally, in contrast to slightly older children's performance in a similar task (Shusterman et al., 2008), children failed to use relative-distance information to disambiguate the ends of the linear array; they appeared to treat the two ends of the line interchangeably.

Moreover, one could reasonably object to our claim to have demonstrated abstract map use. Our maps were not entirely devoid of visual similarity to their referents, as they were roughly of the same color and shape. To what extent do children rely on similarity between symbols and referents to make use of maps? To explore this question, a second experiment tested children's ability to interpret a map that had *no representation of the referent objects at all*, showing only an abstract representation of a triangular enclosure that surrounded them (see Figure 1). In addition to testing the limits of children's reliance on iconicity in interpreting symbols, this study affords a different test of young children's map reading abilities. At least one prior study (Vasilyeva & Bowers, 2006) reported better map-reading performance when the map was a connected triangle as opposed to the three apex points that were used in Experiment 1. This finding motivates a further exploration of 2.5 year old children's map-reading abilities.

Experiment 2

Experiment 2 puts the hypothesis that toddlers can derive geometric information from abstract maps to a stronger test by representing the triangular layout from Experiment 1 without any depiction of the target objects themselves, instead using the map to represent the shape of a triangular "house" in which the three buckets are found (Table 1 and Figure 2). The triangular object array used in Experiment 1 was placed within a 3D triangular enclosure, and the map made reference to the array solely by the presence of a triangular outline denoting this enclosure (see Figure 1). To designate the target object, the puppet pointed to an empty corner of the triangle. The task therefore required children to grasp the correspondence between real-world objects and a representation that contains no markings whatsoever for those objects. Because children in Experiment 1 (and prior studies: see Dehaene et al., 2006; Izard & Spelke, 2009; Lourenco & Huttenlocher, 2008; & Shusterman, Lee & Spelke, 2008; Vasilyeva & Bowers, 2006) were insensitive to sense information, in Experiment 2 we tested only for their sensitivity to distance/angle, and therefore included tests only at the apex location and one of the base locations.

Method

The method was the same as Experiment 1, except as indicated.

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Participants—16 children (9 females) participated in this experiment, ranging in age from 2;0 to 2;7 (*M* = 2;6). Five more children failed to complete the experiment due to fussiness or distraction.

Materials and apparatus—The three buckets from Experiment 1 were arranged in an isosceles triangle and surrounded by a red enclosure 1.5m long, .9m wide and .3m tall. The map consisted of a red outline triangle (7cm base, 12.5cm height).

Design, procedure, and analyses—No warm-up trials or linear trials were given. All children received two test trials, one at the distant location, and one at the proximate location furthest from them (A and C in Figure 2, respectively). The enclosure surrounding the buckets, and its representation on the map, were labeled as "Kermit's house." When indicating the correct location on the map, the experimenter first pointed to each corner of the triangle and said, "there is a bucket in this part of the house, a bucket in this part of the house, and a bucket in this part of the house." Then he had Kermit point to one corner to indicate the target ("Kermit's favorite bucket is here, in this part of the house"). Note that, because only one proximate location was designated as target, we cannot interpret performance at that location as indicating sensitivity to sense, as it could also depend on a preference for that particular location. As such, we analyze only sensitivity to distance/angle in the present analyses, using the same method as in Experiment 1: correct use of distance/angle was analyzed by collapsing across the two similar corners, scoring children as correct when they searched at either proximal corner when one of those corners was target, and comparing this measure across the two trials to chance (50%).

Results and discussion

There were no effects of gender on the performance variables of interest, so the following analyses collapse across this variable.

Location-memory checks—Children pointed correctly on 61% of the location-memory checks, pointing to the apex when it was the target (73%) and avoiding the apex when it was not (82%). Combining across these rates and comparing to a chance level of 50%, children pointed reliably better than chance, $t(14)$[6] = 4.21, $p < .001$, suggesting sensitivity to distance and/or angle information in encoding the 2D targets. Finally, children's overall correct pointing in Experiment 2 (61%) did not differ from Experiment 1 (54%), $t(33) = .84$, *ns*.

Placing trials—Children's placing data for Experiment 2 are graphed in Figure 2. Children placed Kermit in the correct 3D location on 57% of trials. As in Experiment 1, children showed sensitivity to distance/angle: they placed Kermit at the apex location when it was target (56%) and avoided the apex when it was not (81%), $t(15)$ against 50% chance = 2.58, $p = .021$. Finally, there was no significant difference between placing on triangle trials in Experiment 1 (45% correct) and Experiment 2 (57% correct), $t(34) = .94$, *ns*.

[6]The degrees of freedom here and below reflect the fact that two children refused to point on distant trials and once child refused to point on a proximate trial. Their data on choice of referent were included in subsequent analyses.

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In summary, children could use a map of a triangular array that had no actual markings for the entities in the array. Experiment 2 thus suggests that young children can achieve representational insight into a symbol that minimally depicts the appearance of the referent array, and it further confirms the conclusion of Experiment 1 that 2.5-year-old children can spontaneously derive the abstract geometric properties of angle or relative distance from an abstract visual symbol for use in a navigation task.

Although performance in Experiment 2 did not differ reliably from performance on the corresponding trials of Experiment 1, children performed at least as well, and possibly better, on the more abstract geometric map task of Experiment 2. This finding is consistent with Vasilyeva and Bowers' (2006) finding that 3- and 4-year-old children had much more success in a map task when walls enclosed a triangular layout of three buckets as compared to when the buckets were presented alone.

General Discussion

Across two experiments, 2.5-year-old children used purely geometric maps—they interpreted a set of abstract 2D markings as referring to an array of 3D objects that were individuated only by their spatial positions relative to one another. Children's performance on these tasks attests to early-developing spatial and symbolic abilities, which we discuss in turn.

At an age at which representational understanding is just beginning to develop, children can use a symbol whose referents are distinguished only by metric information of angle or distance. Children represented at least some of the spatially invariant properties that link a map to the world to which it refers despite differences between the map and array in size, mobility, orientation, dimensionality and perspective. The present research therefore suggests that by age 2.5 children can extract spatial ("where") information and not just identity ("what") information from visual symbols, and that they do so in the absence of any informative spatial language or explicit instructions about the map-room relationship.

Second, these experiments reveal an early ability to interpret highly *abstract* symbols—both in the sense of abstracting away from the embedded perspective of the array towards a birds-eye view, and in the sense of providing few visual cues to the identity of the referents—including a symbol with no markings whatsoever for most of the 3D objects it referred to. The maps used in the present studies, even though they matched their referents in approximate shape and color, provided no identifying cues about each target and were far more abstract than the images used in prior studies on early symbolic understanding. These studies give an existence proof that young children can interpret even images that do not look like what they represent, and therefore cast doubt on the suggestion that 2-year-old children can only interpret pictures to the extent that they can call up unique names for each referent (Callaghan, 2000). However, the findings still leave open different possible roles for language in the development of symbolic understanding, because the process of language acquisition is well underway at the ages we tested, and because both the maps and the locations they depicted were described verbally.

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An enticing possibility hinted at here is that children's intuitions about maps were not driven by specific experience with maps—indeed, during informal interviews with parents after the session, no parent reported using maps with their child. There is no doubt that children of this age are steeped in visual symbols, and that there is spatial information latent in pictures: even cartoon drawings generally tend to represent entities as being in a particular spatial configuration. Nevertheless, the maps that we presented to children differed markedly from the pictures children typically encounter. They were more abstract, they were presented at a perspective (the bird's-eye view) that is extremely rare not only in the 3D environments that children perceive but in the pictures that depict them, and they were rotated into different orientations throughout the study. Moreover, children made sense of these maps without any training or feedback. If children extrapolated from their experience with pictures to solve our tasks, then they must represent the geometrical structure of pictures with a high degree of flexibility and abstractness.

It is important also to locate the present research within the context of the larger literature on developing map-reading skills. In particular, we are still in need of an explanation for why children succeeded when in prior studies *older* children had difficulty using geometric strategies in similar tasks. We give 4 possible answers to this question. 1) Our paradigm was based on a method proven successful with 4- and 5-year-old children (Shusterman, Lee & Spelke, 2008), hence there is in fact no direct contradiction between the present results and past research. 2) Our method tested for simple geometric relations using small arrays with only a few objects in each, in contrast to other tests of map-reading that used denser, larger-scale arrays (e.g., Liben & Yekel, 1996). 3) Children tend to perform better on placing tests like the present one than on the retrieval tests used in most prior map-reading studies (see, e.g., DeLoache & Burns, 1994; Huttenlocher, Vasilyeva, Newcombe & Duffy, 2008). 4) Finally, the higher degree of iconicity in prior studies may have hindered geometric processing by privileging attention to visual cues over spatial cues. Our maps may have implicitly served to orient attention to spatial information by using only spatial cues as identifying information.

On the other hand, one might wonder why children did not perform better in our tasks, if by age 2.5 children are already relatively proficient picture-users and have well-developed spatial navigating abilities (e.g., Landau, Spelke & Gleitman, 1981; Huttenlocher & Newcombe, 2000). Note first that even adults typically have difficulty using sense information in maps, and that navigation by purely geometric maps continues to develop progressively into adolescence (Izard & Spelke, 2009). Moreover, the present tasks only measured spontaneous use of spatial information, since there was no corrective feedback given on children's object placement trials. An initial non-spatial strategy, then, would have gone uncorrected. By using same-name objects as targets, moreover, we produced a particularly stringent test of map use that required that children ignore the correspondence between the label of the correct location and those of each distracter. Finally, whereas the triangle test could be solved by mapping the exact angle information from the map to the array, the linear test could be solved only by performing a scale transformation and responding to the objects' relative distances. Such transformations often are difficult for very young children (e.g., Huttenlocher, Newcombe & Vasilyeva, 1999).

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Many further aspects of map reading were not tested by our experiments. In particular, our maps referred to a small number of objects in a small room, whereas most maps depict large-scale spaces that cannot be seen from a single vantage point. Many studies make clear that much experience is needed to master modern mapping conventions, and that difficulty interpreting complex metric maps persists even in adulthood (see, Liben, 2009, for a review). More generally, although our experiments show conclusively that children used geometric information in the present tasks—in particular, distance or angle in the triangle arrays and the topological property of betweenness in the linear array—they leave open precisely what geometric information children encoded in our experiments, and at what level that information was represented. We view this issue as the task of future research. In summary, the present studies suggest a markedly early development of understanding geometric symbols, and add support to the claim that fundamental aspects of map reading come naturally to young children.

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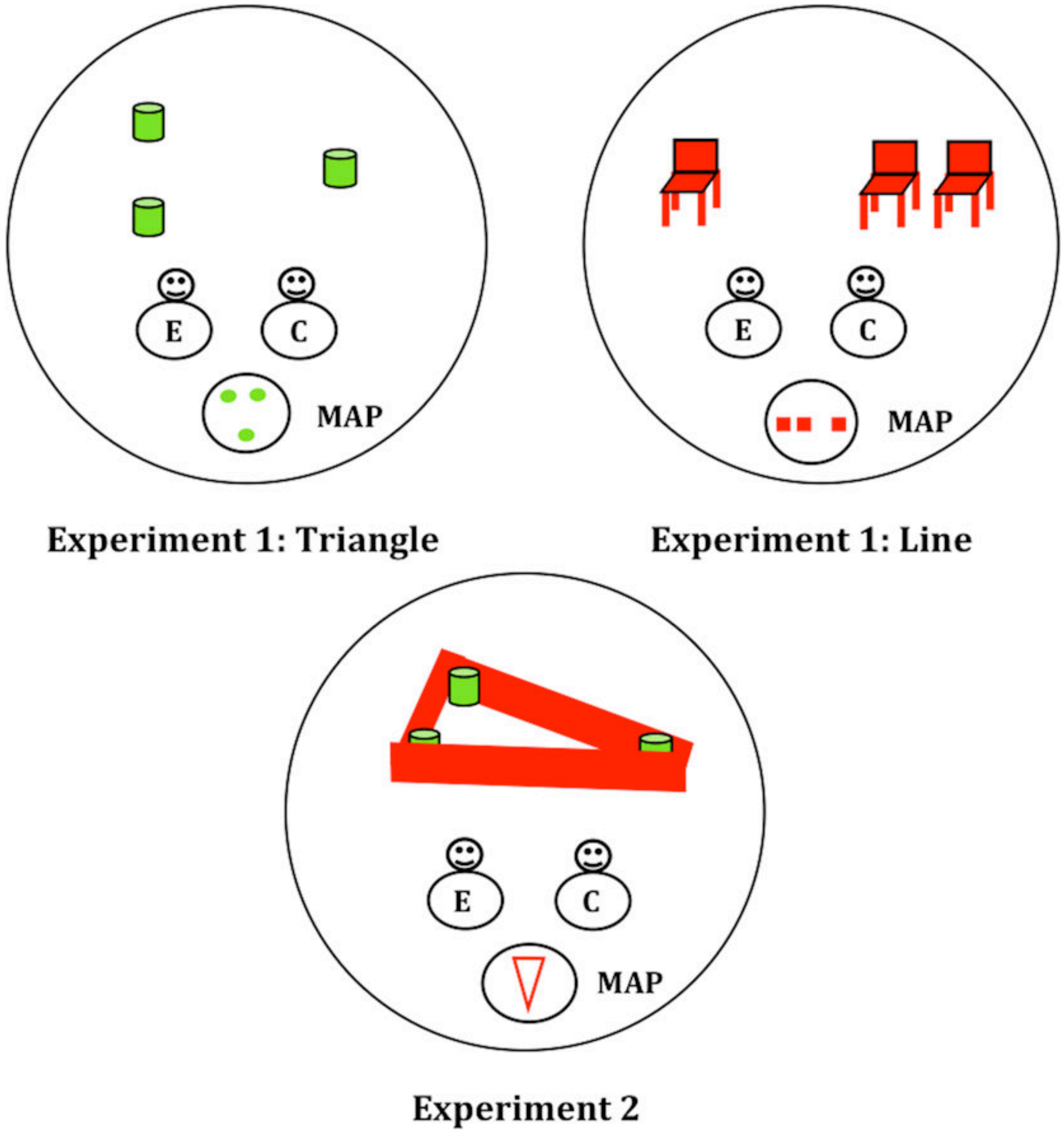

Figure 1.

Schematic diagrams of the experimental set-up for test trials in Experiments 1 and 2. E indicates the position of the experimenter, C indicates the position of the child, and MAP indicates the position of the map (note that the orientation of the map relative to the array varied across trials).

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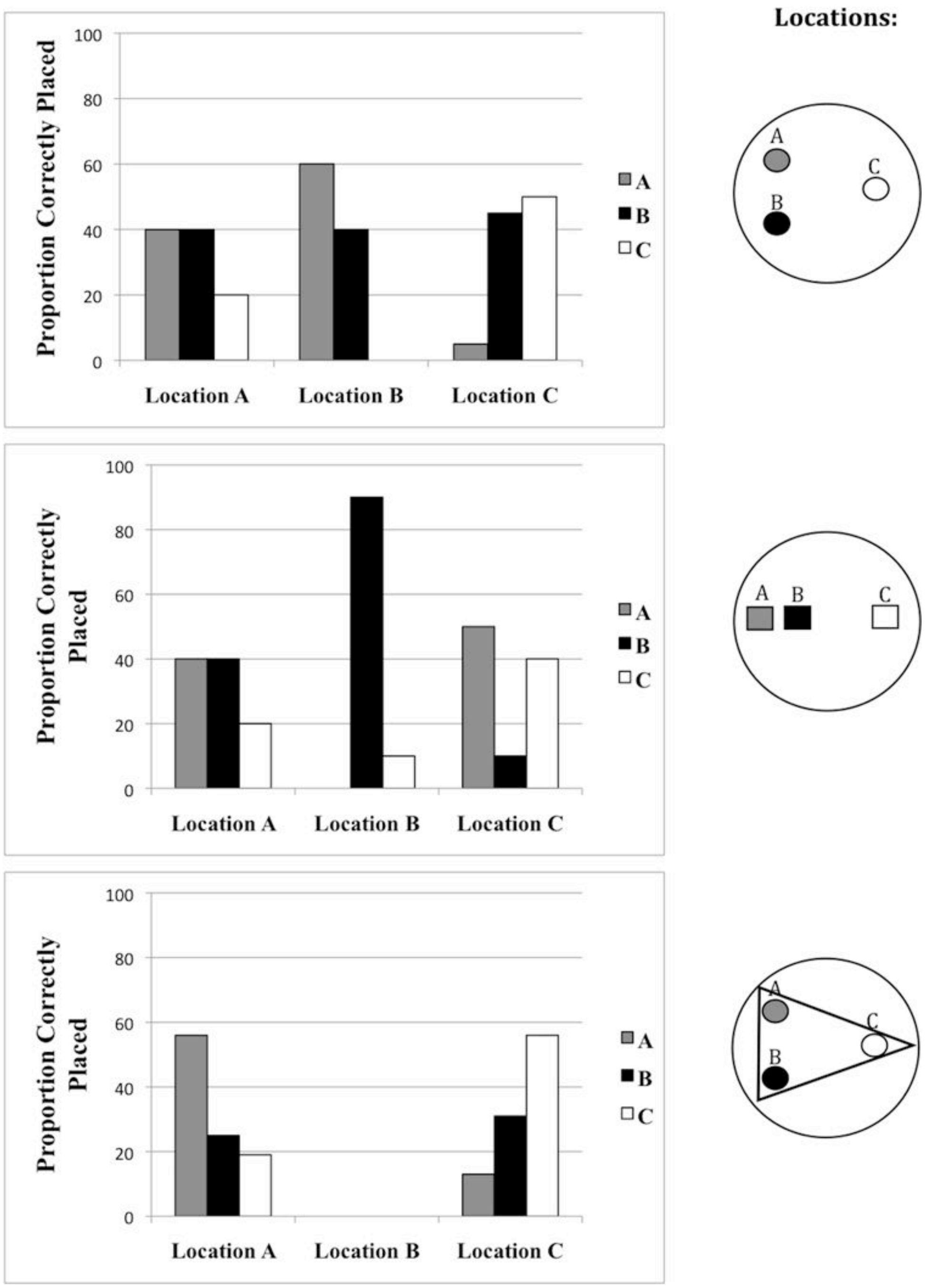

Figure 2.

Each graph shows the proportion of correct placing at each location (indicated in the schematic diagrams to the right of each graph), as a function of the correct target location. The top graph shows data for the triangular array in Experiment 1, the middle graph shows data for the linear array in Experiment 1, and the bottom graph shows the data from Experiment 2. Note that only locations A and C were tested in Experiment 2.

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Table 1

Phase	Procedure	Experimenter's script
Warm-up	*Objects present: red box, green bowl*	
Pointing	1. The training objects are arranged, C is told the nature of the game, and the training map is introduced. 2. C faces E with the two training objects and map in between them as E indicates the correct 2D target. Then E asks C to point to the 2D target, and corrects C if choice is incorrect.	1. Kermit has a favorite place to sit. He either likes to sit in the box, or in the bowl. But Kermit is shy and doesn't want to tell us with words which one he likes. He wants to show us with a picture!" [*Map is produced*] 2. Look, it's a picture of the room. There's the box, and there's the bowl. Kermit's favorite is this one here. Can you point to Kermit's favorite one on the picture?
Placing	3. C gives E the doll and asks C to place it in the correct 3D object.	3. Can you put Kermit in his favorite place to sit?
Test (Exp. 1)	*Objects present: three red chairs/three green buckets*	
Pointing	1. Test objects are arranged and the corresponding map is introduced. 2. C and E now sit next to each other with backs to the array of objects. E indicates the correct 2D target and asks C to point to it a total of 4 times.	1. Kermit has a favorite chair to sit in. He's going to show us which one he likes using a picture. [*Map is produced*] 2. Look, it's a picture of the room. There's one chair, and there's the other one, and there's the other one. Kermit's favorite is this one here. Can you point to Kermit's favorite on the picture?
Placing	3. E gives C the doll and asks C to place it in/on the correct 3D object.	3. Can you put Kermit in his favorite chair?
Test (Exp. 2)	*Objects present: three buckets surrounded by a red triangular enclosure*	
Pointing	1. Test objects are arranged and the corresponding map is introduced. 2. C and E now sit next to each other with backs to the array of objects. E indicates the 2D location and asks C to point to it a total of 4 times.	1. Kermit has a favorite bucket to sit in. He's going to show us which one he likes using a picture. [*Map is produced*] 2. Look, it's a picture of the room. There's Kermit's house. There's a bucket in this part of the house, a bucket in this part of the house, and a bucket in this part of the house. Kermit's favorite is this one here. Can you point to Kermit's favorite on the picture?
Placing	3. E gives C the doll and asks C to place it in/on the correct 3D object.	3. Can you put Kermit in his favorite bucket?