Early map use as an unlearned ability*

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Abstract

Four experiments demonstrated that certain fundamental principles of map use can be accessed without any specific training. Results showed that a 4-year-old congenitally blind child with no previous map-use experience could use a 2-symbol map to directionally guide her locomotion in space, with successful location of objects in front of her, behind her, to her left, or to her right. She could do so under conditions where the map and space were aligned in front of her (canonical condition), and under various transformation conditions: sideways translation, front–behind translation, and vertical rotation. In these conditions, there was no straightforward spatial relationship between her position in space, and her represented position on the map; therefore, mental alignments of the map with external space were necessary. Control data from sighted children showed that, by 4 years, they too could interpret and use these maps. Analysis of the requirements of this simple map task suggests that a core of the knowledge required to use maps is a readily accessible product of a spatial knowledge system common to both the blind and sighted.

This paper reports the performance of a 4 year-old congenitally blind child using simple tactile maps for the first time. Her performance suggests that certain fundamental components of map use are accessible without specific prior experience in map reading, and without previous visual experience.

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These suggestions bear on spatial development in blind children as well as the development of map use in all children.

A map is a physical array of symbols whose spatial relationships stand for the spatial relationships among objects in some other physical array. Understanding the nature of a map seems to require several steps. First, one must be able to conceive of each array as a spatially unified whole, rather than a set of unrelated parts. Since perceptual exploration is sequential (Hochberg, 1978), this means we must mentally construct the spatial relationships of the whole from exploring the spatial relationships among its parts. For each such construction, inference rules can then be applied to make predictions about new spatial relationships in the array. For example, if we explore two paths (A–B, A–C) connecting the three objects or points in a triangular array, we then should be able to infer the direction of the third path (B–C) without actually exploring it. The representations and rules supporting such predictions have been called a system of spatial knowledge (Landau, Spelke, & Gleitman, 1984).

A crucial second step is required to understand a map. One must recognize that the elements of one physical array stand for the elements in the other, and that the spatial relationships embodied in the two arrays are related to each other by a particular kind of geometric mapping. Since maps are usually miniature physical representations of some other physical layout, distances between objects are almost always altered—in many cases, by some constant (hence the use of a scale on many maps). However, since maps are typically used to locate objects that are out of sight, angular relationships between objects—directions—are typically preserved. Transformations that preserve angular relationships while altering distances by some constant are in the class of similarity transformations (Gans, 1969). Therefore, we can infer that a fundamental component of map use is the mental alignment via a similarity transformation of two products of spatial knowledge—one mental description of the map, and one of the space it represents. This alignment then allows predictions of certain spatial properties from one physical array (the map) to the other physical array (the space the map represents).

Is understanding this map notion dependent on extended training as to the relationships between the two physical spaces? Or, is it a natural and straightforward extension of the system of spatial knowledge needed to generate new paths from previously experienced ones? At least some aspects of mapping must be explicitly learned, for the formal means for expressing spatial relationships in maps vary widely across history and cultures (see Harvey, 1980). Mapping devices can range from expressing space by a two-dimensional but otherwise veridical picture (e.g., 15th century picture maps) to a three-dimensional but highly schematic array (e.g., Eskimo bas-relief maps in which the
contours of sticks represent shoreline curves). Yet some aspects of map use might reflect the core of knowledge about maps—knowledge that is a precondition for learning about more specific, culturally-determined, mapping devices. The similarity transformation would appear to be fundamental in just this way, as it holds over maps that otherwise possess very different properties (as above). The focus of this paper is the nature of this core knowledge, and the conditions required to initiate understanding of it.

In order to address this issue, we ask how readily a child can understand the map notion, given that she has a system of spatial knowledge, but no previous map-reading experience. The logic of this approach is similar to that of a prior and analogous investigation. Hochberg and Brooks (1962) tested a young child's ability to identify simple line drawings of objects, even though he had never previously been shown any pictures or heard them named. The child could obviously perceive objects prior to test, but had never had training in matching objects to their line drawings. He nevertheless was able to identify the line drawing representations of a set of familiar objects. This study suggests that children can rapidly understand certain external spatial representations of objects—in this case, projective representations—without extensive prior experience interpreting them. A straightforward analogy can be made for children's understanding of maps. By age 2 or 3, children are able to conceive of multi-object arrays as spatially unified wholes, evidenced for example by their ability to make spatial inferences in navigation tasks (Hazen, 1982; Landau, Gleitman, & Spelke, 1981; Landau et al., 1984; Rieser & Heiman, 1982). For example, if a child is walked along two paths holding between two pairs of objects in a triangular array (A–B, A–C), he can then infer the direction and distance of the shortest route holding between the objects in the third pair (A–C). It seems reasonable to ask, then, whether children of this age are also able to understand the external spatial representations corresponding to such arrays—maps—without extensive prior experience interpreting those representations. In particular, we can ask whether these children understand that maps should preserve the angular-directional relationships among objects in the represented array.

At present, no investigations permit a conclusive answer to this question. First, most developmental investigations of map use have studied school-age children's ability to reconstruct familiar arrays (such as the classroom), using detailed miniatures of the objects to be arranged (Golbeck, 1983; Liben, Moore, & Golbeck, 1982; Siegel & Schadler, 1977). These re-creation tasks may have been novel; but most school-age children have certainly had some prior experience manipulating and spatially arranging similar representational objects. When younger children have been tested, pictorial (line drawing) maps have been used to induce location of a hidden object (Bluestein &
Acredolo, 1979). The success of some 3-year-olds is suggestive that the conceptual rudiments required for map use are in place by this age; but two problems prohibit any stronger conclusion. First, children's extensive experience interpreting two-dimensional representations of multi-object arrays (photographs, line drawings of arrays) seems uncomfortably close to the task of interpreting a simple line drawing map of a room. Second, and more important, the task used by Bluestein and Acredolo required that the children locate an object hidden in one of four target boxes, each of which was located on a straight line path between two distinctive landmarks. Successful location of the object could be accomplished by matching the two landmarks to their line drawing representations, plotting a straight line between them, and choosing the box that fell on that line. Such a solution would require that the child preserve the projective properties holding for points on a line (including, for example, the property of "betweeness"), but would not require appreciation of any metric properties. The fact that such a non-metric solution is possible for Bluestein and Acredolo's task precludes any conclusions about children's ability to understand and use the similarity transformation, which is so important to general understanding and use of maps.

**General experimental plan**

In the present report, a young congenitally blind child was selected for study. Two important features of her background motivated this choice. She had already shown the ability to travel freely along known paths in an array and to induce the directions of new paths, thereby demonstrating that she could conceive of the array as a unified whole rather than as a set of unrelated or partially related paths (Landau et al., 1984). Her precocious use of spatial verbs and prepositions confirmed that her organization of space was adequate to support a rich symbolic system (Landau & I.R. Gleitman, 1985). Yet, she had had no map-reading experience at the time of the study. Further, as is reportedly common for blind children (Fraiberg, 1977), she was rather delayed in her use of standard representational items, such as dolls and toy trucks, and did not engage in the representational play typical of sighted children. It was thus possible to test her with the confidence that she had had no experience closely related to the task.

The tests of the child's knowledge of maps were designed so as to elicit evidence of her appreciating and using the angular relationships between objects shown on the map, to guide travel to target objects in a larger space. This required ruling out simple perceptual solutions, such as matching of objects on the map and in the space, or locomotion to some visible target
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(c.f. Blaut, McCleary, & Blaut, 1970)—neither of which would necessarily require the abstract encoding and manipulation of spatial information (see Landau et al., 1984).

First, the child was required to recognize that some abstract symbol could be used to represent an object. In this situation, unlike prior ones, the symbols did not in any way resemble the objects; rather they were rectangular wooden blocks. Second, the subject was required to use spatial-directional information conveyed on the map to locate an object, by noting at minimum the directional relationship between herself and the target. She was required to search an environment that was free of any landmarks that could be perceived at a distance, and could thereby more directly guide locomotion.

Finally, she was required to show evidence of mentally aligning the map with the space it represents. She was therefore tested when the map was presented in a variety of positions, including the “canonical” one (i.e., flat and straight ahead of her). Using a map from any viewing position requires mental alignment of the mental descriptions of the two arrays. But the need for such alignment becomes most obvious under non-canonical viewing conditions. Here, we wished to discover whether alignment was possible under any non-canonical conditions. We therefore used right–left translations, front–behind translations, and vertical rotations, eliminating horizontal rotations because of the widespread difficulties they seem to cause both adults and children (Tversky, 1981; Bluestein & Acredolo, 1979). In right–left translations, the map itself (hence the group of symbols on the map) is moved to the viewer’s right or left. In this way, a symbol might be to the viewer’s right (if the map is to his right); but the symbolized object may be to the viewer’s left in space. In front–behind translations, the map (hence the symbols) is presented in front of the viewer, but the symbolized objects are located behind him. In vertical rotations, the map is tilted vertically (as in reading a book), thereby moving all symbols on the map to a vertical position, but the symbolized objects still form a horizontal array in space. In short, the relationships within the map are preserved, while the relationship between viewer and map changes relative to the canonical position. The ability to compensate for any of these changes would provide clear evidence for a young child’s appreciation that such mental alignments may be required under certain circumstances, and for her ability to effect them when so required.

To summarize, the experiments required that a child with no previous map-reading experience interpret and use the angular spatial relationships between highly abstract symbols to directionally guide navigation. The question at issue was whether the blind child would understand and be able to use the relationship between map and represented space, and under what circumstances of training.
Subjects
The blind subject was a 4-year-old girl, Kelli, who was totally blind from birth due to Retrolental Fibroplasia. She participated in a series of studies on knowledge of space and language, and was given a psychological assessment yearly as a part of that study (see Landau & Gleitman, 1985). In each assessment, she was found to fall within the normal range of development (measured by the Bayley Scales of Infant Development and the Stanford-Binet Tests of Intelligence). Kelli participated in a series of experiments on spatial knowledge between the ages of 2 years, 7 months and 4 years, 5 months (Landau et al., 1984). Preliminary observations on her map use were made at age 4 years, 6 months, following the procedures of Condition 1 outlined below. Kelli successfully found the target object on three of three trials. Accordingly, more formal testing was conducted between the ages of 4 years, 9 months and 5 years, 11 months (exact ages for each experiment given below).

The sighted subjects were six children between the ages of 4 years and 4 years, 1 month. There were three girls and three boys.

Method
Kelli participated in four separate experiments (henceforth “conditions”) conducted at different times. The sighted subjects each participated in a single (comparable) four-condition experiment. In all experiments, children were asked to find an object in a room. The only information they were given about the object’s location was conveyed on a map which represented their own position and that of the target in the room (see Procedure, below, for details). For Kelli, the layout and number of trials varied slightly over conditions, as described below. For the sighted subjects, the room layout remained constant across conditions, with four possible target locations (see Figure 1). Each sighted subject received a total of 24 trials, with 6 in each of the four conditions.

In Condition 1 for Kelli (age 4 years, 9 months; 13 trials), targets were located either in front of her, or to her right or left, and the map was presented to her held flat and directly in front of her (see Figure 1, targets X1, X2, X3). Targets X1 and X2 were presented four times each, and X3 was presented five times. Later analysis revealed that one trial with X2 was biased.

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1The sighted subjects were younger than Kelli, but were in the same grade (nursery school). Kelli was held back one year in school during the time of the study, so the controls were education-mates, if not age-mates. It is worth noting that Kelli’s lag in school indicates that she is not an “exceptional” blind child.
Figure 1. Room layout for conditions. \(X_1, X_2, X_3, \) and \(X_4\) are target locations for the array. Kelli was tested in the 10 ft \(\times\) 10 ft space shown; the sighted children were tested in a comparable 8 ft \(\times\) 10 ft space which occupied all but the lower row of squares shown. Thus, the back wall was located at the bottom of the figure for Kelli, but at the next row up for the sighted subjects. \(K\) represents Kelli's location for Conditions 1, 2, and 4, and the sighted children's location in all conditions. In Condition 3 (front–behind translation), Kelli was positioned one block ahead of \(K\), to equate distance between herself and the targets \((X_2, X_4)\). The target locations were indicated as above on the sighted children's maps, but the actual targets were located behind the wall at each location. (Scale: 1 block = 2 ft square)

because of the introduction of a new map symbol, and this trial was discarded for further analysis, leaving twelve trials. Sighted subjects received six trials, with two targets each to the front, right, and left.

In Conditions 2, 3 and 4, the map was presented under various transformation conditions, each of which required mental alignment of the map with the viewer's position beyond that required in Condition 1. In Condition 2 for Kelli (age 5 years, 1 month; 12 trials), she was asked to find an object which was again located either in front of her, or to her right or left \((X_1, X_2, X_3,\) Figure 1), but the map was presented eight times on her right and four times on her left, randomly determined. This resulted in five trials where target position and map presentation matched (i.e., both to Kelli's right or both to her left), and seven trials where they did not match. Each target was presented four times. Sighted subjects received six trials, with two targets each to the front, right, and left. The map was presented to the child's right on half of the trials, and to her left on the other half, with the restriction that no trial contain a left–right match between target position and map presentation.
Condition 3 (Kelli, age 5 years, 11 months; 8 trials) was the front–behind analogue to Experiment 2, with targets located either in front of or behind Kelli (X2, X4, Figure 1) and the map always presented flat and directly in front of her. Each target was presented four times. Sighted subjects received six trials, all of which showed targets behind the child. These six trials were later compared to the six “front” trials across the other conditions.

In Condition 4 (Kelli, age 5 years, 1 month; 8 trials\(^2\)) target objects were located as in Condition 1, and the map was presented in front of Kelli, upright at approximately a 60 degree angle. Two targets were to be presented three times each, and one twice; but an experimenter error resulted in presentation of targets X1 and X2 twice each, and target X3 four times. Within each condition, all orders of target presentation were randomly determined. Sighted subjects received six trials, with two each to the front, right, and left.

Each sighted subject was given the Canonical condition first, followed by Conditions 2 and 4, in counterbalanced order. Since Condition 3 had only targets behind the subject, these trials were randomly ordered within presentation of trials in Conditions 2 and 4; this was to prevent subjects from developing a strategy of always looking for the toy behind them (which could have occurred if the six trials of Condition 3 had been presented en masse). The order of presentation of target locations was randomly determined within each condition for all children (except for Condition 3, whose trials were presented as described above).

**Materials**

The maps used with Kelli were 10 × 10 in. sheets of cardboard, gridded with ink into 2 in. squares, to represent the 10 × 10 ft room in which she was tested (of course, the blind child could not see the grid). Each map displayed two wooden blocks: one \(1\frac{3}{4} \times 1\frac{3}{4} \times 1\) in., representing Kelli herself, and one \(1\frac{3}{4} \times 3\frac{1}{2} \times 1\) in., representing a familiar toybasket. The blocks were placed on the map using double-faced masking tape, so that they could be easily moved between trials. Block placement varied according to the condition (as described above, and see Figure 1). The maps used with the sighted subjects were identical, except that they were made of 8 × 10 in. sheets of cardboard, to represent the 8 × 10 ft room in which they were tested.

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\(^2\)This condition is presented fourth, although it was conducted when Kelli was the same age as in Condition 2. This non-chronological presentation facilitates the logical flow of the report, and does not change the results or conclusions in any way.
Procedures

In all four conditions, Kelli was tested in a 10 × 10 ft room which was free of audible landmarks, and whose floor was gridded with masking tape into 2-ft squares. In each condition, she was carried into the testing room, and placed in a child’s chair (see Figure 1). Since Kelli’s map-reading experience was confined to these experiments, it is important to describe E.’s presentation of the map to her; for this constitutes a description of the specific experience afforded her before she was tested on her ability to use maps.

Kelli was shown the map of the room, and allowed to explore it. The map was described to her as she explored it, as follows: “This is a map of the room. It tells you where things are in the room. This is the whole room (guiding her hands over the entire map). And this is you, where you’re sitting in the room (guiding her hands to the block representing her). And this is the toybasket (guiding her hands to that block). Here’s where you are, and here’s where the toybasket is (touching each at the appropriate time).” She was asked to identify each symbol and did so easily.

She was then tested, by asking her to find the toybasket, “Can you find the toybasket in the real room?” Once Kelli began to move, E. remained at the child’s chair, and spoke only after Kelli had travelled at least 2 ft from the chair. At this point, E. sometimes spoke, encouraging Kelli to continue on her route. The pattern of speaking, while not predetermined by E., was not systematically related to Kelli’s success or failure on the trials. Moreover, since one of the measurements of success or failure was facing direction after 2 ft of travel (see below), this measure was completely independent of the E.’s comments. A trial was terminated when Kelli reached one of the three 2-ft squares flanking the target (one in front, one on its left, one on its right), or if she began to move from the starting point in a direction away from the target. As the results will detail, this latter case rarely occurred, but when it did, the trial was terminated after Kelli had moved 2–3 ft out from her starting point. The former trials were terminated as successes, and the latter as failures (see Results for details on criteria for success/failure). Only Kelli’s independent locomotion was used for data analysis. After terminations of successful trials, E. sometimes gave Kelli verbal directions on how to make contact with the target (e.g. “a little to your right”). After each trial, Kelli was picked up and carried out of the room, where she waited with a research assistant until E. signalled that the room and map had been rearranged for the next trial. At this point, she was carried back into the room, placed in her chair facing front, and the next trial began.

As detailed above, in Condition 1, the map was presented flat to Kelli, and directly in front of her, on her lap (see Figure 1). This was also the presenta-
tion method for Condition 3. Conditions 2 and 4 entailed presenting the map in a non-canonical position. When this occurred, Kelli was not specifically instructed in any way. Rather, E. made one off-hand comment at the start of the experiment, “I’m just going to hold the map this way.”

Sighted subjects were tested in much the same way as Kelli had been, with several slight modifications. They were tested in an 8 × 10 × 4 ft featureless surround which was constructed using a wooden frame covered with an opaque pale yellow fabric. This surround formed a “room” within a larger room. The floor was gridded into 2-ft squares. Before the experiment, the child was told that E. was going to hide a toy behind the walls of the “room”, and that his job would be to find it. Each child was then walked into the experimental room with his eyes shut, and seated in the small chair. He was then allowed to open his eyes, and was shown a map of the room designed precisely like Kelli’s maps. He was instructed about the map the same way that Kelli had been, except that E. pointed to the parts of the map as she spoke, rather than the (unnecessary) haptic exploration guidance. Testing followed the procedures for Kelli, with some minor modifications: on each trial, sighted subjects were asked to walk to the place in the surround behind which the toy was hidden (“Can you walk to where the toy is hidden?”). After each trial (walking), E. went to where the child was standing, peered over the top of the surround, and told the child that he was either correct (if he had walked to the correct wall) or incorrect (if he had walked to one of the other three walls). Then the child was walked out of the room, where he waited with a research assistant until the room and map had been changed for the next trial.

Method of analysis

All experimental sessions were videotaped and later transcribed to indicate the children’s paths of locomotion. These transcriptions consisted of recording the child’s position and direction of facing every 3 s during independent locomotion, and connecting these positions with a line representing the child’s path of locomotion. Each such transcribed path was submitted to several measures (detailed below) determining accuracy relative to the goal. Number correct using these measures was the dependent variable.

Initial turn

This measure assessed whether, after the first 2 ft of movement, the child’s position was better adjusted to the target than it was to any of the other possible target locations. For targets straight ahead, a response was considered correct if, after 2 ft of movement, the child was in the 2-ft square directly
in front of the starting point. For targets behind, a correct response was one falling in the square directly behind the starting point. For targets to the right (or left), a correct response fell to the right (or left) of the square directly in front of the starting point. Note that it would be possible for a child to occupy the correct square, but face in a direction away from the target. This never occurred, however; if a child fell in the correct square (as defined above), he was also facing the target. Therefore, measuring the correct square is equivalent to measuring whether or not the child is moving toward the target.

For this and all subsequent measures, three analyses are reported for each condition. (1) Number correct over all trials of each condition was assessed using a Binomial test, to determine whether the children’s performance was at chance level. Random probability of success was defined separately for each measure. For initial turn, it depended on the number of possible target locations, since just one (“correct”) square corresponded to each location. For Kelli in Conditions 1, 2, and 4, there were three possible target locations, hence $p = .33$; in Condition 3, there were two possible locations, hence $p = .50$. For the sighted subjects, there were four possible target locations in each condition, hence $p = .25$. Probabilities for the children’s performance are reported separately for Kelli, and for the sighted subject whose performance falls at the lowest end of the range for all sighted subjects. (2) Proportion correct over all trials was computed, and Kelli’s performance was compared to that of the sighted subjects by determining whether or not her scores fell within their range of scores. The non-parametric assessment of these patterns would normally be conducted using the Randomization test; however, given the small numbers of subjects, even the most extreme pattern (Kelli’s scores falling outside the sighted range, either above or below it) could not achieve a significance level of $p < .05$. Hence comparison of Kelli’s scores to the sighted range will be reported directly, with no further statistical analysis. (3) Kelli’s number correct on the first trial to each location was compared to her number correct on the last trial to each location. This allowed us to assess whether there was any evidence of improvement over trials.

**Final position**

This measure assessed whether or not, at the termination of a trial, the child’s position was better adjusted to the target than it was to any other target location. Two separate measures were made, corresponding to a fine directional accuracy, and a gross directional accuracy.

A. **Fine directional accuracy** In Kelli’s case, the toybasket subtended approximately one 2-ft square. Allowing for a small area on each side of the target, she was scored correct if her final position fell within a 40 degree
segment extending from the starting point and surrounding the target; at its largest point, this segment covered approximately 2 ft on either side of the target's midpoint (see Figure 2). Similarly, each sighted subject was scored as correct if his final position fell within the two 2-ft squares subtending the target's specified location (see Figure 2). Random probability of success depended on the number of possible 40 degree segments surrounding the starting point and extending to the boundaries of the space. We assume that if the child is moving randomly, she has an equal opportunity to fall in any one of the nine 40-degree segments circling the starting point, hence the random probability of success \( p = .11 \).

**B. Gross directional accuracy** Here, a child was scored correct if his final position fell within a 90 degree segment surrounding the midpoint of the target; this segment covered approximately four feet on either side of the target's midpoint (and was slightly less than the length of one wall; see Figure 2). The randomness assumption is the same as for the fine directional accuracy measure; but this time assumes a one-in-four chance of ending up in one of the four 90-degree segments surrounding the starting point. Hence the random probability of success \( p = .25 \).

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**Figure 2.** *Sample segments for successful trials, using two different criteria. Cross-hatching indicates the 40 degree segment for target X1; stippling indicates the 90 degree segment for target X3. (Note: the sighted children's array effectively eliminated the bottom row of squares).*
Results

Proportions correct for all conditions are shown in Table 1. They indicate that the task was quite simple for the sighted children, with almost perfect performance by most subjects. Kelli also performed quite well, in all conditions. However, as Table 2 shows, comparison of her first trial data with her last trial data suggests some improvement over trials in most conditions. This did not occur for the sighted subjects.

Condition 1

Here, the map was presented flat, and directly in front of the children. Both Kelli and the sighted children performed well above chance on all measures. First, Kelli’s initial turns were correct on nine of the twelve trials ($p = .003$, Binomial test\(^3\)). The sighted subjects were correct on a mean of 5.50 of their six trials with a range of 5 to 6 ($p = .004$, Binomial test). Second, Kelli was quite accurate in moving all the way to the correct target location: she fell within the correct 40 degree segment and within the correct 90 degree segment on nine of the twelve trials ($p < .0001$ and $p = .0004$, respectively, Binomial tests). The sighted subjects fell within the correct 40 degree segment on a mean of 5.17 trials (range, 4 to 6), and within the correct 90 degree segment on a mean of 5.67 trials (range, 5 to 6; $p$ values < .002 and .004, respectively, Binomial tests\(^4\)). Kelli’s performance was within the sighted range for fine directional accuracy, and slightly outside it for the other two measures (see Table 1). Furthermore, Kelli’s and the sighted children’s errors were evenly distributed over target position, ruling out the notion that the children’s performance was due to some strategy of always moving towards one particular location independent of what was indicated on the map.

A comparison of Kelli’s first trial for each target location to the last trial for each location shows a slight improvement (see Table 2). On the first trial to each location, she was successful on all measures for two of the three

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\(^3\)Kelli’s achieved numbers correct reported for this condition are slightly different from those reported in Landau et al. (1984). This is because, first, one trial was discarded due to a confound (see p. 207), leaving a total of twelve trials. Second, on two trials, Kelli’s comments conflicted with her motor behavior (e.g. she said “To my right”, then moved left). In the current analysis, these trials were considered failures, even if the child did move in the correct direction. This resulted in a changed value (success to failure) for two trials on one and two measures, respectively.

\(^4\)Although the sighted subjects could have solved this map problem by counting the numbers of squares intervening between themselves and the target location, there was no evidence they did so. Moreover, the fact that they took straight routes to the goal (leading them diagonally across several squares) suggests strongly that their movements were guided by directions inferred from the map, not by the indicated number of squares (which would lead to a city-block type of path).
Table 1. *Proportions correct over different conditions*

<table>
<thead>
<tr>
<th>Condition 1</th>
<th>Initial turn</th>
<th>Fine directional accuracy</th>
<th>Gross directional accuracy</th>
<th>Maximum number correct</th>
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<tr>
<td>(Canonical)</td>
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<tr>
<td>Kelli</td>
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<td>.75</td>
<td>.75</td>
<td>12</td>
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<td>Sighted*</td>
<td>.92</td>
<td>.86</td>
<td>.94</td>
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<tr>
<td>(Range)</td>
<td>.83–1.00</td>
<td>.67–1.00</td>
<td>.83–1.00</td>
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<td>Condition 2</td>
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<td>(Lateral translation)</td>
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<tr>
<td>Kelli</td>
<td>.92</td>
<td>.58</td>
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<tr>
<td>Sighted</td>
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<td>(Range)</td>
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<tr>
<td>Sighted</td>
<td>.67b</td>
<td>—</td>
<td>—</td>
<td>6</td>
</tr>
<tr>
<td>(Range)</td>
<td>.00–1.00</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Condition 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Vertical rotation)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kelli</td>
<td>.89</td>
<td>.25</td>
<td>.62</td>
<td>8</td>
</tr>
<tr>
<td>Sighted</td>
<td>.89</td>
<td>.80</td>
<td>.97</td>
<td>6</td>
</tr>
<tr>
<td>(Range)</td>
<td>.50–1.00</td>
<td>.67–1.00</td>
<td>.83–1.00</td>
<td></td>
</tr>
</tbody>
</table>

* Mean proportions correct for the six sighted subjects
* This proportion represents pointing responses only, see text.

locations. On the last trial to each location, she was successful on all measures to all locations. The sighted subjects showed no such effect: on their first trials to each location, all subjects but one were successful for all measures. The last subject failed on one measure for one of the trials. This ceiling performance indicates that the sighted subjects found the task quite easy. Kelli’s good performance on the first trials also suggests that she readily understood the task: her slight improvement over trials (shown in the other experiments as well, see below) probably indicates some kind of warm-up effect.

**Discussion of Kelli’s performance in Condition 1**

The results of this experiment suggest that Kelli could understand and use a simple map to guide navigation. However, before accepting this conclusion it is important to rule out the possibility that Kelli’s locomotion was guided
Table 2. *Kelli’s performance on first and last trials over conditions*

<table>
<thead>
<tr>
<th></th>
<th>First trial</th>
<th></th>
<th></th>
<th>Last trial</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial turn</td>
<td>Final 40</td>
<td>Final 90</td>
<td>Initial turn</td>
<td>Final 40</td>
<td>Final 90</td>
</tr>
<tr>
<td>Condition 1</td>
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<td></td>
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<tr>
<td>(Canonical)</td>
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</tr>
<tr>
<td>Front</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Right</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Left</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
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<td>Condition 2</td>
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<td>(Lateral translation)</td>
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<tr>
<td>Front</td>
<td>+</td>
<td>–</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Right</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Left</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Condition 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Front-behind translation)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Front</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Behind</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Condition 4</td>
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<tr>
<td>(Vertical rotation)</td>
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<tr>
<td>Front</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Right</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Left</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Totals correct</td>
<td>7</td>
<td>6</td>
<td>8</td>
<td>11</td>
<td>7</td>
<td>10</td>
</tr>
</tbody>
</table>

Correct responses are indicated by a plus (+), incorrect by minus (–).

by perceptual information afforded in the room. One such possibility is that subtle sounds in the room could have guided her locomotion (although there were no apparent noises in the room), and another is that she used echolocation to localize the target. This possibility also seems highly unlikely, since the target was quite small and lacked a uniform surface off which sound waves could bounce. Moreover, Kelli’s performance did not seem good enough to suggest perceptually-guided locomotion. She rarely came into contact with a target on her own—a behavior one might expect if subtle sounds or echoes were guiding locomotion.

Some relevant evidence on Kelli’s spatial behavior in other contexts suggests that neither of these possibilities is likely.

At 48 months, Kelli was tested on her ability to localize the toybasket (as well as a small chair and a small table) in the absence of any information about its location (Landau et al., 1984). The experiment was conducted in
the same room as the current experiment. Objects were placed in precisely the same locations as in the current experiment, and Kelli was started at the same starting point (among others). She was given the same command—to find the target—and was sporadically encouraged, as in this experiment. However no information at all was provided about the object’s location; Kelli had not previously walked to any of the target locations, nor had she been shown a map of the room as in the present experiment. Her performance on the same measures as above showed that she was unable to localize the target under these conditions: her initial turns were toward the target on four of twelve trials ($p = .23$); she fell within the 40 degree target range on two out of twelve trials ($p = .24$), and within the 90 degree target range on two out of twelve trials. Further, Kelli knew that she did not know where she was going, for on every trial, she repeatedly asked for help, e.g., “Would you please help me?” or “I can’t find it”. These comments were never seen in any other experiment on Kelli’s navigational ability, nor was it ever seen in any of the experimental conditions reported here. Thus, it seems plausible to conclude that Kelli’s spatially oriented behavior in the present experiment was due to guidance by her knowledge of the spatial relations shown on the map, not by some external source.

**Condition 2**

Here, the map was presented flat, and to the children’s right or left. Again, all children performed well above chance. Kelli’s initial turns were correct on eleven of twelve trials ($p < .0001$, Binomial test); the sighted subjects were correct on a mean of 5.50 trials (range, 5 to 6; $p < .004$, Binomial test). In addition, Kelli fell within the correct 40 degree segment on seven of twelve trials ($p = .0001$, Binomial test) and within the correct 90 degree segment on eleven of twelve trials ($p < .0001$, Binomial test). This latter finding suggests what is confirmed by observation of the trials: when Kelli missed the narrower segment, it was because she made too sharp a turn, but nevertheless generally in the correct direction. The sighted subjects performed similarly: they fell within the correct 40 degree segment on a mean of 4.33 trials (range, 3 to 6, $p = .02$, Binomial test), and within the correct 90 degree segment on a mean of 5.50 trials (range, 5 to 6, $p = .004$, Binomial test). Kelli fell within the sighted range on all three measures. Three of her errors occurred on trials 3

3The probability level reported here ($p = .23$) is slightly different from that reported by Landau et al. ($p = .12$). This is because Landau et al. used a random probability of .50 (towards or away from the target), while the present report uses a random probability of .33 for strict comparability to the other initial turn measures reported in this paper.
Early map use

with targets to the right, and two with targets to the left; however, only one of these errors occurred on a trial where the presentation position conflicted with the target position, that is, when the target was to Kelli's left, and the map (hence symbolized target) was presented to her right. The sighted subjects' errors were not systematically related to the target position, or to the presentation position of the map.

Kelli's performance improved over trials. On the first trial to each location, she achieved success on all three measures for the first location, and on two of the three measures for the second location, but had no success on the third location. On the last trial to each location, she achieved success on all measures for two locations, and two of three measures for the third. We can conclude from her pattern of performance that Kelli was able to account for a left–right translation of the map in space.

Condition 3

Here, Kelli showed that she could effect a front–back translation as well as a right–left one. On seven of the eight trials, her initial turns were correct (p = .03, Binomial test). On six of the eight trials, she fell within the correct 40 degree segment (p < .0002, Binomial test), and on all eight of the trials she fell within the correct 90 degree segment (p < .0001, Binomial test). The comparison with sighted subjects for this condition can only be suggestive, for when the sighted subjects were correct on these trials, they did not walk to the goal—instead, they just pointed behind them. Presumably, this was because their chair was positioned quite close to the back wall (see Figure 1) hence they thought that pointing was as good as walking. Although the data are not completely comparable to the other conditions, still the number of correct responses (pointing in the correct direction, behind them) can be considered. Asking merely if the subjects pointed in the correct direction (i.e., to the correct square, as with the initial turn measure), the sighted subjects were correct on a mean of four out of six trials (range, 0 to 6; p = .18, Binomial test). It is worth noting that three subjects received perfect scores, two were correct on three of six trials, and one child scored zero, with errors on two trials, and either ambiguous behavior or refusal to respond on the other four trials. For the only relevant measure (initial turn), Kelli fell within the sighted subjects' range, at the upper end. On Kelli's first trial to each location, she was successful on all three measures for one trial, and one of three for the other trial. On her last trial to each location, she was successful on all measures for both trials.
Condition 4

In this last condition, the map was presented upright, and directly in front of the children. Kelli again performed well. Her initial turns were correct on six of eight trials ($p = .02$, Binomial test). The sighted subjects were correct on a mean of 5.33 of six trials (range, 3 to 6; $p = .13$, Binomial test). Kelli fell within the correct 40 degree segment on only two of the eight trials ($p = .16$, Binomial test), turning too far in the correct direction on four additional trials. She fell within the correct 90 degree segment on five of eight trials ($p = .023$, Binomial test). The sighted subjects fell within the correct 40 degree segment on a mean of 4.83 trials (range, 4 to 6, $p = .002$, Binomial test), and within the correct 90 degree segment on a mean of 5.83 trials (range, 5 to 6, $p = .004$, Binomial test). Kelli fell within the sighted range for initial turn, considerably outside the range for fine directional accuracy, and slightly outside the range for gross directional accuracy. On Kelli’s first trial to each location, she was successful on all three measures for two locations, and none on the third; on her last trial to each location, she was successful on two of three measures to two locations, and one of three to the third.

Despite their success, it is worth noting that Kelli and two of the six sighted children initially interpreted the vertical presentation mode as representing a vertical space. For example, on the first trial, Kelli commented “It’s just like a hill”. The experimenter replied, “I’m just holding it like this”—after which Kelli commented “Up the hill—up, up, up”. Similarly, two of the sighted children first responded to the vertically presented map by pointing upwards (both trials had targets straight ahead). After the experimenter gave them feedback that the target was not located in the air (see above), they presumably reinterpreted the map as a vertical representation of a horizontal space, since they were correct on the remaining trials. The communality of these interpretations over blindness and sightedness suggests it is a natural initial interpretation—and perhaps a good one: verticality is sometimes represented by vertical displays, for example, three-dimensional representations of mountains, or two-dimensional representations of the different levels of a building.

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*The non-significant performance of the sighted children on the initial turn measure is due to the fact that Binomials were performed on the scores of the subject who fell at the lower end of the range. One subject in this condition achieved only three out of six correct, hence with a random probability of .25, $p = .13$. The mean score for this measure is quite comparable to the mean scores for the other measures.*
Discussion

This series of experiments addressed the question of whether young children require any extended or special training in order to understand a simple map, and use it to navigate through space. In particular, we asked whether children would immediately understand and be able to use the specific set of "stand for" relationships captured by similarity transformations—wherein angles or directions are preserved, but distances are altered. The results suggest that the components investigated here do not require such training; rather, they were quickly understood by a congenitally blind child who had no previous experience interpreting maps or map-like materials. This finding is similar to Hochberg and Brooks’ demonstration that the correct identification of object line drawings does not require extensive experience or training in that medium. Appreciation of explicit representations of space seems to develop in children with little formal training.

From her first exposure, Kelli could use simple tactile maps to locate objects in a room; so could the sighted controls, without directly perceiving any of the targets. The only spatial information afforded these subjects was contained in the map: one object representing the subject, and one object representing the target, positioned relative to the other. An implicit axis was also provided, by presenting the maps in an orientation consistent with the child’s own orientation in the room. From this, the children could derive the direction of the target’s location in the space represented by the map. They thus recognized a correspondence between the map’s reference system and that of the real space, and inferred that the directional relationship holding between the two symbols on the map was identical to that holding between the two objects in the represented space. Finally, the children were able to align these reference systems mentally when necessary, by translation or vertical rotation. In short, they appreciated that the map bore a special geometric relationship to the represented space, and they could use that relationship to infer the location of objects in the space around them.

It is worth noting that the children’s appreciation of angular-directional relationships in the maps counters claims by other investigators that early spatial knowledge—including map use—is topological in nature (Golbeck, 1983; Piaget & Inhelder, 1956). It is quite likely that the task used in this paper forced reliance on a metric (angular) solution, since (in contrast to other studies) other properties such as shape, size, and color of landmarks were not available (cf. Mandler, 1983). However, the fact that this solution was so readily accessible to young children suggests that metric properties and the transformations (such as similarity) that leave them invariant may be a quite basic component of the early emerging human spatial knowledge.
system. In an important sense, knowledge of metric spatial properties is quite fundamental to localization of objects, since it can support accurate inferences even when perceptual information is absent or insufficient to uniquely identify the target. The present results suggest that young children are capable of using these important metric spatial properties even in highly abstract tasks such as map use.

More generally, the findings suggest that map use can arise independent of any specific experience in map reading. Why should this be so? One possibility is that core knowledge of maps is a direct and natural function of the spatial knowledge system required to support other kinds of spatial inferences seen in young children—specifically, those inferences observed in navigation tasks. Consider the requirements of the map task that our subjects performed successfully. In this task, the perceiver must explore the physical array that is a map, and construct a unified spatial description of it, including angles and distances between pairs of objects. He must note his current location in the represented space (e.g. in his chair), and must align both descriptions—of his current position, and of the map. Using the geometric relationship of similarity holding between the two descriptions, he can now apply an inference rule to generate a new directionally-specific path from his current position to the target in space.

Now consider spatial inferences performed by children in navigation tasks. Here the perceiver must again explore a physical space—this time the paths relating objects in a larger array. As he moves along the paths, he constructs a unified description of the array, including angles and distances. In order to make a spatial inference, he then must locate himself in that physical space. He can now align the two descriptions—of his current position and of the stored array. Then, given that he understands that both angles and distances must be internally consistent for any given array, he can infer which direction and what distance to travel to reach another object shown on the stored array.

Described in this way, using a map to generate new routes is quite similar to using a stored spatial description constructed through travel to generate new routes. There are only two differences. In the case of map use, the child must recognize an equivalence relationship between the landmark by which he locates himself and its symbol on the map. There is no such relationship in the case of making an inference based on information gained through travel alone. Most crucially, the child must recognize that physical maps—but not mental maps—bear the special geometric relationship of similarity to the real arrays they represent. Since similarity transformations presuppose the existence of metric properties, they can be viewed as a natural extension of the spatial knowledge system used to guide navigation.

This view makes several predictions, which are confirmed by existing liter-
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First, it predicts that if a person understands the nature of maps, then using maps to develop knowledge of an area should be at least as efficient as actually travelling the area. This is true for adults (Thorndyke & Haycs-Roth, 1982), although there are no comparable studies of children. Second, it predicts that rudimentary map use might appear as soon as the child shows evidence of spatial knowledge together with the appreciation of the meaning of physical symbols. Several investigators have placed the appearance of detour formation around the end of the second year of life (Piaget, 1954; Rieser & Heiman, 1982). Piaget argued that this reflects onset of a general representational stage, which permits the operation of various symbolic functions. Whether or not this is so, evidence suggests that the onset of primitive map use may occur around this time. For example, Bluestein and Acredolo (1979) found that approximately half of the 3-year-olds in their study understood the task. Similarly, Premack (personal communication) reports that 2-year-olds show very little understanding of simple three-dimensional maps, but that 3-year-olds perform very well. This is in dramatic contrast to the extremely poor performance of chimps in using these same maps (Premack & Premack, 1983). In fact, the Premacks report that the chimps were successful at using indicated locations in one array to infer locations of corresponding objects in a second array only when the first array they used (i.e. the “map”) was an identical replica of the target room, complete with full-sized furnishings. This, together with the results of the present study, strongly suggests that the understanding of maps as arrays which correspond to an original via a similarity transformation is part of a spatial knowledge system whose early and natural emergence is peculiar to humans.

Finally, although the focus of this study was not blind children in particular, the findings are clearly relevant to theories of spatial development in the blind. It is well known that blind adults can use properly constructed maps (Berla, 1982; Leonard & Newman, 1967). Yet, observations from Fraiberg (1977), Bower (1977), and others suggest that young congenitally blind children have particular difficulty developing two crucial precursors to map use: a conception of space as a unified whole rather than a set of unconnected or partially connected paths, and a symbolic function that permits the use of some arbitrary objects as “stand-ins” for spatially related objects in the real world. Fraiberg suggested that the general capacity to symbolize can be derailed easily without vision, and described difficulties in achieving such presumptive symbolic functions as object permanence, language, and play. Others have suggested that blindness biases towards mental representations of space that are more sequential and fragmentary, and less easily organized and manipulated than those constructed by the sighted (Millar, 1975; 1976; O’Connor & Hermelin, 1978; Warren, Anooshian, & Bollinger, 1973).
The present report cannot adjudicate the issue of whether the spatial representations underlying map use are identical in blind and sighted children. But it does suggest that blindness need not deter the child's understanding of some basic, yet quite abstract, functions of spatial knowledge that seem to require both an appreciation of symbolic devices, and the capacity to construct unified representations of a space.

Kelli's—or any child's—ability to use maps depends on and ultimately requires the ability to construct a mental description of space. This description can then be addressed in a variety of ways: by information gained through haptic or locomotive exploration, through language or maps. Sighted children can additionally use visual information for such purposes, but there may not be anything privileged about vision in effecting this translation. Such indifference to the modality of experience could help explain how a young blind child could come to use her spatial knowledge in the abstract way shown by her understanding of maps.

References


Résumé
Quatre expériences démontrent que les enfants sont capables d'employer certains principes gouvernant l'utilisation d'un plan sans entraînement particulier. Dans ces expériences, une fille aveugle de naissance, âgée de quatre ans, qui n'avait jamais utilisé de plan, a montré qu'elle était capable de s'orienter dans une pièce grâce à un plan et de localiser correctement un objet qui était placé soit devant elle, soit derrière elle, soit à sa gauche, soit à sa droite. Elle y parvenait non seulement lorsque le plan et l'espace lui étaient présentés en alignement (situation canonique), mais aussi lorsqu'on faisait subir au plan diverses transformations: translation de côté, rotation de 180 degrés, et rotation verticale. Comme dans ces situations il n'y avait pas de relation spatiale évidente entre la position de l'enfant dans la pièce et sa position sur le plan, elle devait mettre en correspondance mentalement le plan et l'espace extérieur. Les mêmes expériences conduites sur des enfants normaux ont montré que, vers l'âge de quatre ans, ils sont aussi capables d'interpréter et d'utiliser ce type de plan. L'analyse de cette tâche simple indique que certaines des connaissances requises pour l'utilisation d'un plan sont fournies par un système de connaissances spatiales commun aux voyants et aux non voyants.