Obstacle perception by congenitally blind children

DANIEL H. ASHMEAD, EVERETT W. HILL, and CHARLES R. TALOR
Vanderbilt University, Nashville, Tennessee

The ability to perceive objects from a distance and navigate without vision depends principally on auditory information. Two experiments were conducted in order to assess this ability in congenitally blind children aged 4 to 12 years who had negligible amounts of visual experience or formal mobility training. In Experiment 1, children walked along a sidewalk toward a target location to get some candy. A box was placed along the path on some trials, and the children were instructed to avoid the box if it was present. The children spent more time in the region just in front of the box than in the region just behind it, indicating that they perceived the box and acted so as to navigate around it. In Experiment 2, children attempted to discriminate whether a nearby disk was on their left or on their right. The children performed at above-chance levels, again indicating distal perception of objects. The results of both experiments suggest that blind children with little or no visual experience or formal training utilize nonvisual information, presumably auditory, to perceive objects. The specific nature of this auditory information requires further investigation, but these findings imply that the underlying perceptual ability does not require experience in spatial vision or deliberate training and intervention.

Navigation through cluttered environments depends on perception of the locations of objects and surfaces so that obstacles can be avoided and clear pathways can be used. Although vision is ideally suited for this task, both blind observers and blindfolded sighted observers can locomote without collisions through spaces containing large objects (Supa, Cotzin, & Dallenbach, 1944; Worchel, Mauny, & Andrew, 1950). Various explanatory processes for this ability to navigate without vision have been proposed over the years, including "facial vision" resulting from sensitivity to changes in air pressure near surfaces, a "sixth sense" unique to blind persons, and echolocation based on reflected sounds. The ability is mediated by sensitivity to auditory information, probably in the form of reflected sounds or sound shadows. For example, Supa et al. (1944) found that both blind observers and blindfolded sighted observers who could otherwise stop 1-2 m in front of a large panel collided with it if their hearing was strongly attenuated. Attenuation of other potential sensory information, such as tactile or thermal stimulation, did not adversely affect performance, so it was concluded that auditory information was necessary and sufficient.

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Nonvisual obstacle perception has been investigated by experimental psychologists, notably Dallenbach and his colleagues, beginning with Supa et al. (1944), as well as by orientation and mobility instructors, who train visually impaired people, usually older children and adults, in techniques for independent travel (Welsh & Blasch, 1980). Since no systematic attempts to evaluate this ability developmentally have been reported, one purpose of the present study was to extend the investigation of nonvisual obstacle perception by testing young, congenitally blind children. The testing of this population provides a basis for assessing the roles of visual experience and formal mobility training in the development of nonvisual perception of obstacles. The subjects in the present study had minimal visual experience, as defined in terms of age of onset and degree of visual impairment, and they had negligible amounts of formal mobility training. A related purpose was to explore how this perceptual ability might be integrated with ongoing, functionally important behavior. Previous studies have typically involved overt verbal or gestural reports of the perception of obstacles. Although such measures are well suited for investigations of the informational basis for obstacle perception, they do not indicate how the information is utilized for functional goals such as moving from one place to another (Strelow & Brabyn, 1982).

Children were tested in two experiments, both involving nonvisual object perception at a distance. The task in Experiment 1 was to walk along a sidewalk on which boxes had been placed as obstacles to locomotion. The question was whether and how the children would make appropriate locomotor adjustments to navigate the route.

In Experiment 2 (which was based on studies done by Kellog, 1962, and by Rice, Feinstein, & Schusterman, 1965), children were seated at a table and presented with disk-shaped objects to the right or left. They made forced-choice judgments regarding the side on which the disk had been presented.

EXPERIMENT 1

The classic test of nonvisual obstacle perception in the Dallenbach studies was to have people walk toward an obstacle, usually an upright Masonite panel slightly taller than a person, stopping to raise their hand when they first perceived it ("first perception") and stopping again when they felt that they were about to contact it ("final appraisal"). Typical distances were about 6 ft for the first perception and 1-2 ft for the final appraisal (Ammons, Worchel, & Dallenbach, 1953). This test has been used with great success in the attempt to identify the information underlying the ability of nonvisual obstacle perception, the general conclusion being, as noted above, that auditory information is necessary and sufficient. However, a more naturalistic measure was needed to reveal how nonvisual obstacle perception is coordinated with ongoing spatial behavior and to circumvent the logistical constraint that young children would not understand or comply with the classic task. In Experiment 1, children were asked to walk along a sidewalk on which they knew there might be obstacles, in order to retrieve some candy placed at the end of the route. The sessions were videotaped and later examined for changes in locomotion that reflected perception of the obstacles and appropriate locomotor adjustments. The net effect of these adjustments was that the children spent additional time in the region just in front of the obstacle.

Method

Subjects. The subjects were 10 visually impaired children, ranging in age from 5.3 to 12.5 years. Each child was totally blind or had light perception only, listed as beginning by the time of birth. All were residential students at the Tennessee School for the Blind and were at age-appropriate grade levels. All children had normal hearing and no nonvisual handicaps. Four of the children had some history of formal orientation and mobility training and 6 did not—the 4 with training are designated in Table 1. This was a group of relatively high-functioning children with little or no developmental history of unimpaired visual experience.

Apparatus and Procedure. The study was conducted on a sidewalk in the middle of a large quadrangle on the campus of the Tennessee School for the Blind. The sidewalk was surfaced with concrete and bordered by grass at the same level of the concrete, so there was little risk of the children's falling or tripping. There were no obstacles such as trees or poles in the immediate area of the sidewalk. The children were very familiar with this area, having traversed it routinely during day-to-day activities. A 27-ft length of the 6-ft-wide sidewalk was designated as the experimental space, as is shown in Figure 1. The task on each trial was to walk from the starting point along the sidewalk to the end point, which was called the "candy store." At the end point, there was a chair with a piece of hard candy on it. The chair was placed on a piece of carpet, so that the children would notice the carpet as they neared the candy. On obstacle trials, a box was placed on the sidewalk between the starting and end points.

Prior to testing, each child was familiarized with the experimental space. This consisted of two guided walks from start to end with no obstacles, an opportunity to feel and explore the boxes while off the travel path, and a guided walk from start to end with the medium box at the center of the pathway. The child was told that sometimes there might be a "roadblock" on the way to the candy store, and sometimes not. On each trial, the child was positioned at the starting point facing the end point and instructed, "You're facing the candy store. Now I want you to go get some candy." The children were not given any explicit directions about what to do regarding the obstacle box or about whether they should make sounds as they walked along. The children wore blindfolds throughout the session, so that those who had some light perception could

Table 1
Proportions of Trials on Which More Time Was Spent Before Obstacle Than After Obstacle

		Obstacle Size				All Obstacle Trials	Control		All Control Trials
		Medium		Large			Near	Far	
Subject	Age	Near	Far	Near	Far				
Younger Age Group									
1	5.3t	2/3	1/3	3/3	2/3	.67	1/3	3/3	.67
2	6.6	2/3	2/3	2/3	3/3	.75	2/3	1/3	.50
3	6.7	2/3	3/3	2/3	2/3	.75	1/3	2/3	.50
4	6.9	1/3	3/3	0/3	0/3	.33	0/3	2/3	.33
5	7.0	2/3	1/3	3/3	1/3	.58	1/3	2/3	.50
Total		.60	.67	.67	.53	.62	.33	.67	.50
Older Age Group									
6	8.0	2/3	1/3	2/3	2/3	.58	2/3	2/3	.67
7	8.6	3/3	3/3	3/3	2/3	.92*	2/3	1/3	.50
8	8.7t	3/3	3/3	3/3	3/3	1.00*	1/3	1/3	.33
9	10.0t	3/3	3/3	3/3	3/3	1.00*	2/3	1/3	.50
10	12.5t	3/3	2/3	3/3	3/3	.92*	1/3	2/3	.50
Total		.93*	.80*	.93*	.87*	.88*	.53	.47	.50
Total		.77*	.73*	.80*	.70	.75*	.43	.57	.50

Note—Proportions that are significant by a sign test at the .05 level (two-tailed) are designated by asterisks. Children with some history of formal orientation and mobility training are designated by a "t" following their age.

Figure 1. Task environment for Experiment 1. Dashed lines show 5 ft-long locomotor regions before and after the box, which were superimposed on video recordings during data scoring.

not use it. The sessions were videotaped from a 90° side view for later analysis. The testing was conducted at a time of day and in a location such that potential cues from wind and light shadows (which produce a temperature cue) were minimized—wind and sun were at the children's backs.

The experimental design included variation of the obstacle size and distance as well as whether an obstacle was present or not. There were two sizes of obstacle box, medium (2 × 2 × 2 ft) and large (4 ft tall × 3 ft wide × 2.25 ft deep), both constructed of ¼-in. thick masonite. The obstacles were presented at two distances, near (8 ± 3 ft) and far (15 ± 3 ft) from the start. The specific locations of the starting point and the obstacles were varied by several feet across trials, in order to prevent the children from using cracks or other variations in the sidewalk as cues to the obstacle locations. Every child received 3 trials for each combination of obstacle size and distance, for a total of 12 obstacle trials. In addition, every child received 6 control trials on which no obstacle was present. The 18 trials were presented in the same random order for each child, with obstacle and control trials mixed within blocks and with the restriction that identical trials not occur consecutively. After each trial, the child was guided back to the start, and the experimenter then set up the obstacle for the next trial. On control trials, a box was placed on the sidewalk briefly and then removed, to control for temporal or auditory cues associated with box placement. The children listened to music played over earphones between

trials, in order to prevent them from hearing the box placement for the next trial. The sessions typically lasted 45–60 min.

The videotaped sessions were coded for the amounts of time spent in the 5-ft region in front of the box and the 5-ft region behind the back surface of the box (see Figure 1). On control trials, when the sidewalk was not blocked by a box, an imaginary box was used to define these regions. The rationale for coding the time spent in these regions was that if children perceived the obstacles, they would spend more time before them than after them, in order to notice and begin to navigate around them. Two coders viewed the videotapes and independently measured the time spent in each locomotor region, using stopwatches to the nearest hundredth of a second. The coders showed high rates of agreement, to within 0.29 sec on 79% of the trials and 0.49 sec on 90% of the trials, so the measurement error was well under 0.5 sec. The correlation between the coders' times was 0.98. For any given child, the data from one coder were used for analyses.

Results

The central question is whether the children detected the obstacles, and if so, whether this detection varied across age, distance of obstacle from starting position, and size of obstacle. The measure of time spent before or after the obstacle location was entered into two separate analyses of variance, one on the obstacle trials and one on the control trials.

Obstacle trials. The design for the analysis of obstacle trials involved locomotor region (before obstacle, after obstacle) × age (younger, older based on a median split) × obstacle size (medium, large) × obstacle distance (near, far) × trial (1, 2, 3), with repeated measures on all factors except age. In this analysis, evidence for detection of the obstacle would consist of significant effects of locomotor region and other factors interacting with locomotor region.

There were several significant effects involving the locomotor region factor. As is shown in Figure 2, on obstacle trials significantly more time was spent in the region before the obstacle than in the region after it [$F(1,8) = 9.63, p < .02$], the means being 5.05 sec before and 3.80 sec after the obstacle. The interaction of locomotor region and obstacle distance [$F(1,8) = 10.27, p < .02$] suggested that the effect of locomotor region was stronger when the obstacle was near than when it was far from the start. Tukey's *HSD* tests indicated that on near trials, the time spent before the obstacle was significantly greater than the time spent after it, but on far trials, the difference was not significant. In sum, children spent more time in the region before the obstacle than they did after it. This difference was statistically significant for the two distances combined and for the near distance by itself.

Although there were no significant effects involving age, some effects approached significance. The tendency to spend more time before than after the obstacle was stronger in the older than in the younger children, as is shown by the interaction of locomotor region and age [$F(1,8) = 4.28, p = .072$]. The younger children had means of 4.23 sec before and 3.81 sec after the box, and the older children had corresponding means of 5.88 and

Figure 2. Time spent in locomotor regions before and after obstacle location, for locations near and far from start on experimental and control trials.

3.79 sec. The three-way interaction of locomotor region, age, and obstacle distance also approached significance [$F(1,8) = 5.08, p = .054$]. The younger children had means of 4.48 sec before and 3.94 sec after the box at the near distance, and 3.97 sec before and 3.68 sec after the box at the far distance. The older children had means of 6.39 sec before and 3.58 sec after the box at the near distance, and 5.37 sec before and 4.00 sec after the box at the far distance.

The only other significant effect was the interaction of obstacle distance and obstacle size [$F(1,8) = 8.50, p < .02$]. For the near distance, the mean times for medium and large obstacles were 4.70 and 3.76 sec, respectively, whereas for the far distance, the corresponding times were 3.78 and 4.73 sec. Since these findings did not involve the key variable, locomotor region, they were not explored further.

Control trials. The analysis for control trials involved age (younger, older) $\times$ obstacle distance (near, far) $\times$ trial (1, 2, 3) $\times$ locomotor region (before obstacle, after obstacle), with repeated measures on the latter two factors. (Obstacle size was irrelevant for this analysis, since the control trials did not provide a contrast that was comparable to the medium vs. large obstacles; but obstacle distance was relevant, because it was plausible that locomotor speed might change with distance from the starting position.) The pattern of findings on control trials showed no overall tendency for the children to spend more time before the imaginary obstacle location than after it. This is shown in Figure 2, where findings from the real obstacle trials and the control trials are compared. This indicates that the greater amount of time spent before than after the obstacle when it was actually present cannot be

attributed to a general tendency of the children to accelerate as they walked down the path. There was one significant effect, for the three-way interaction of age, obstacle distance, and locomotor region [$F(1,8) = 5.36, p < .05$]. The younger children averaged 3.34 sec before the obstacle and 3.91 sec after it when it was near the start, compared to 3.71 and 3.35 sec when it was far from the start. The older children averaged 4.20 sec before the obstacle and 4.19 sec after it in the near condition, and 4.36 sec before and 4.83 sec after it in the far condition. On post hoc tests, none of the pairwise comparisons for the cells of this three-way interaction was significant.

Analysis of contacts with obstacle. The children spent more time before than after the obstacle location when an obstacle was present, but not on control trials. This suggests that they detected the obstacle, but a possible confounding factor is that the children contacted the obstacle on many trials and therefore had tactual confirmation of its location. Contacts occurred on 63 out of the total of 120 obstacle trials. The greater time that children spent before the obstacle than after it might be attributable to their having walked faster after they knew from touching it that the obstacle would no longer be in their way. (A related explanation, that the extra time before the obstacle was spent in actually touching it, is not tenable, because the measure of time before the obstacle was stopped as soon as contact occurred.) Two sets of findings indicate that the before/after time differences were not an artifact of the children's having contacted the obstacle.

First, this interpretation implies a prediction about performance on the obstacle trials compared to the control trials that was disconfirmed by the findings. If children simply walked faster after having contacted the obstacle,

then they should have spent the same amount of time *before* the obstacle location on obstacle and control trials, and less time *after* the obstacle on obstacle trials than on control trials. This pattern of findings was not obtained, as is shown in Figure 2. Direct statistical comparison of obstacle and control trials shows that the children spent significantly more time before the obstacle location on obstacle trials (5.05 sec) than on control trials (3.90 sec) [$t(178) = 3.48, p < .001$]. The time spent after the obstacle location on obstacle trials (3.80 sec) did not differ from the time on control trials (4.07 sec) [$t(178) = 1.00, n.s.$]. This pattern of findings is consistent with the hypothesis that the children anticipated the position of the obstacle when it was present, and it is inconsistent with the hypothesis that the children simply walked faster after having contacted the obstacle.

The second set of findings related to the artifact of contacts with the obstacle is from the trials on which there was no contact with the obstacle. On such trials, the occurrence of before/after time differences would have to be attributed to factors other than contact with the obstacle. Analyses based only on the noncontact trials indicated that the before/after differences were, if anything, even larger than in the analyses based on all trials. Collapsing across age, obstacle size, and obstacle distance, significantly more time was spent before the obstacle (5.48 sec) than after it (3.84 sec) [$t(112) = 3.92, p < .001$]. The before/after time difference was also significant for the near and far obstacle distance trials considered separately. For the near trials, the mean time before was 6.00 sec and the mean time after was 3.67 sec [$t(44) = 3.04, p < .01$]. For the far trials, 5.12 sec were spent before and 3.95 sec after [$t(66) = 2.53, p < .02$]. In summary, the finding, based on all obstacle trials, that the children spent more time before than after the obstacles was also observed on the subset of trials on which there was no contact with the obstacle.

Performance of individual children. In order to assess the performance of individual children, the time measure was coded for each trial according to whether more time was spent before or after the obstacle location, with the former case counted as a success for purposes of conducting sign tests. Table 1 shows these data for individual children in each condition, as well as collapsed across conditions and subjects. Among the older children, 4 out of 5 performed above chance on obstacle trials. Although none of the younger children was significantly above chance on obstacle trials, two of them (Subjects 2 and 3) had high percentages of obstacle trials on which they spent more time before than after the obstacle. With so few trials (12 or fewer), the sign test is quite stringent in that there is little allowance for "missed" trials, but it is apparent from Table 1 that there was an overall tendency to spend more time before than after the obstacle.

Discussion

The findings from Experiment 1 indicate that congenitally blind children can use nonvisual information to de-

tect locomotor obstacles. Children were observed walking along a sidewalk that sometimes contained obstacles, a test situation that closely approximated everyday travel conditions. When an obstacle was present, the children spent more time in the region just before the obstacle than they did after it. They also spent more time in the before region when an obstacle was present than they did on control trials with no obstacle. These time differences were typically 0.5–3 sec, which is consistent with our qualitative impression that detection of the obstacle was integrated with ongoing locomotion and did not lead to long delays in progress along the route. Even so, it should be noted that the children walked quite slowly and deliberately in this task, at a rate of 1–2 ft/sec. Casual observation of these children between trials and in other settings indicated that they walked faster, comparable to sighted children, when they were confident that a path was clear. The slower pace in the experimental task suggests that obstacle detection is facilitated by a slower approach. Only one child produced sounds in a seemingly deliberate manner (handclapping), but footstep sounds accompanied walking in all of the children. The role of sound cues in obstacle detection is considered further in the General Discussion section below.

In contrast to what has been done in most studies of nonvisual obstacle perception in adults, the children in this experiment were not asked to make an explicit response to the obstacle. It is interesting to compare the children's behavior with that of adults in other studies, with regard to how far in advance the obstacle can be perceived. In the present study, the time spent in the region 5 ft before the obstacle was measured, because inspection of the videotapes indicated that when overt responses to the obstacles were made (pointing, vocalizing), they tended to be made within about 5 ft of it. In a comparable adult study described earlier, Ammons et al. (1953) tested blindfolded sighted adults who walked along a sidewalk and detected large Masonite boards set up perpendicularly to their line of travel. The subjects stopped and raised their hands when they first perceived the obstacle and when they felt that they were about to contact it (final appraisal). Typical values (from their Table 2) were 6.06 ft for the first perception and 1.65 ft for the final appraisal. This agrees quite well with the finding in the present study that the children responded differentially when they were within about 5 ft of a locomotor obstacle, the same distance at which adults reliably detect obstacles. We did not code the data for time spent farther than 5 ft before the obstacle, but extensive viewing of the videotaped data suggested that it is unlikely that the children detected it from much farther than about 5 ft. Other studies of adults, particularly some blind adults who were tested indoors, have shown somewhat earlier first perception (e.g., Supa et al., 1944), but even indoors, the modal value has been within about 5–6 ft. This suggests that the functional utility of nonvisual obstacle detection, at least for obstacles not much taller than a person's height, is restricted to a fairly close range, but still far enough to allow evasive action during locomotion.

EXPERIMENT 2

In Experiment 1, children's walking along a path was found to be delayed by a few seconds as they approached fairly large obstacles. Experiment 2 was designed to assess perception of fairly small-scale features of the environment, the specific task being to discriminate on which side disks of various sizes were presented. This provided a more explicit response measure than did the locomotor task of Experiment 1, in that children made a forced-choice response on each trial about which side an object was presented from. At the same time, the task corresponds to functionally important behavior such as the act of locating things while one is seated at a table or the avoiding of overhanging objects while one is walking.

The task was modeled after several studies of blind and sighted adults (Kellogg, 1962; Rice et al., 1965; Rice, 1969). In those studies, psychophysical methods had been used to estimate the discriminability of properties such as the distance, size, and texture of disk-shaped objects. For example, Kellogg (1962) placed a 12-in.-diam disk 2 ft (the reference position) from subjects and measured their discrimination of subsequent changes in the disk's distance from them. One blind subject discriminated distance changes as small as 4.3 in. The subjects in both the Kellogg and the Rice studies were encouraged—indeed required—to produce vocalizations during the task, and the published reports emphasize that their performance was mediated by echo detection. Accordingly, the children in our Experiment 2 were encouraged to make whatever sounds they wanted to during the task.

The spatial discrimination investigated in this experiment consisted of whether a disk was located to the right or left side (45°) of the straight-ahead position. Disk size was varied in an attempt to find the smallest disk for which the left/right discrimination could be made reliably.

Method

Subjects. The subjects were 15 visually impaired children ranging in age from 4.1 to 12.5 years. Ten of the children had participated in Experiment 1, and the remaining 5 resembled them in being congenitally blind (totally blind or with light perception) but relatively high functioning.

Apparatus. A circular disk was presented on either the left or the right side of the child, as the child sat at a table in the middle of a large room. Ten disks of ¼-in.-thick Masonite were cut to diameters ranging from 2 to 20 in. in 2-in. increments. The disks were attached by wires to brackets that were in turn suspended from guy wires at a distance of 24 in. from the child's face at angles of 45° right and left, so that the front faces of the disks were perpendicular to the child's position.

Procedure. On each trial, the child reported which side the disk seemed to be on. The children were told that disks of various sizes would be used, but that there would always be a disk on one side or the other. They were asked to handle the various disks for a few minutes before testing began. The children wore a blindfold throughout the session. On each trial, the experimenter hung a disk on one side and a spare bracket on the other, in order to prevent the children from using the experimenter's movements or any sound from the bracket to solve the task. The side on which the disk was hung varied randomly from trial to trial, in a different order for each

child. The children were given as long as they wanted in order to say which side the disk was on. They were allowed to make sounds and move their heads, but they were instructed not to reach out for the disks. Once they responded, the experimenter provided appropriate verbal feedback (e.g., "Good job, you got it right," vs. "You missed that one, let's try another.") and allowed them to touch the disk. The datum for each trial, then, was the child's two-alternative, forced-choice response about which side the disk was on.

From trial to trial, disk size varied according to a 2-down, 1-up staircase psychophysical algorithm (Levitt, 1971). Testing began with the 20-in. disk. The disk size was decreased after two consecutive correct trials and increased after a single incorrect trial (if changes below 2 or above 20 in. were called for, then the 2- or 20-in. disk was used, respectively). The initial decrease in disk size was always from 20 to 10 in. The next change (either an increase or a decrease) was by 4 in., and all subsequent changes were by 2 in. As a check on the children's task interest, after any two consecutive incorrect trials, the 20-in. disk was presented repeatedly until a trial was correct, and then testing was resumed with the disk size that had been used prior to this jump to the 20-in. disk. Testing continued until the experimenter judged that the children were no longer sufficiently on task, typically as indicated by statements such as, "I don't want to do this anymore."

Results

Although the adaptive psychophysical procedure was designed to obtain thresholds on individual children, most of the children lost interest in the task before enough trials to estimate a threshold were run. The mean number of trials was 25.1, with a range of 9 to 44. Rather than continue the sessions beyond the children's span of interest, it was decided to analyze the data in terms of percentage correct. These results are summarized in Table 2, which shows the performance of individual children (data collapsed across stimulus levels) and at each stimulus level (data collapsed across children). Statistical evaluation was based on the chance level of correct responding, which was 50%. Each child's performance collapsed across disk sizes was evaluated with a sign test. For each age group, and for the two ages combined, performance was evaluated for each disk size, again using sign tests. Findings significantly above chance are indicated by asterisks in Table 2.

The pattern of findings indicates that the children discriminated the side on which disks were presented. Nine of the 15 children performed significantly above chance, and the rest did well on at least a few disk sizes. Because individual children contributed disproportionately to the findings for different disk sizes, threshold estimates might be misleading. However, disks as small as 12 in. in diameter were readily discriminated by the majority of the children, as indicated by the individual data in Table 2.

It may be noted with respect to the column totals in Table 2 that performance appeared to be worse for the three largest disks than for smaller disks. This counterintuitive finding may reflect the context within which these disk sizes were presented. The 16- and 18-in. disks were not used often, because the adaptive psychophysical procedure concentrated most of the trials at smaller disk sizes. When these disks were presented, it was mostly to chil-

Table 2
Performance on Disk Task by Individual Children and by Age Groups

Subject	Age (years)	Disk Size (inches)										All Disks
		2	4	6	8	10	12	14	16	18	20	
1	4.1					0/1		0/2	3/5	3/5	5/6	.58
2	5.0					0/1	0/1	4/4			3/3	.78
3	5.1					0/2	2/3	2/2	1/3	4/6	6/6	.68
4 (1)	5.3t					0/2	2/3	2/3	0/2	2/2	5/9	.52
5	6.1				2/2	2/2	3/6	6/6	2/2		2/2	.85*
6 (2)	6.6	0/1	2/3	4/5	2/2	2/2					2/4	.71
7 (3)	6.7				0/1	2/4	4/5	2/2	2/2		2/2	.75*
8 (4)	6.8		1/2	4/4	2/2	2/3	3/3	3/4	2/2		4/7	.78*
9 (5)	7.0			0/1	1/4	6/7	2/2				4/4	.72*
Younger Total		.00	.60	.77*	.64	.59	.85*	.71	.50	.69	.77*	.70*
10	7.6					1/2	4/6	4/5	6/6		4/4	.83*
11 (6)	8.0		0/1	2/3	2/2	2/2					5/10	.61
12 (7)	8.6			1/3	5/7	7/12	12/12	2/2			2/3	.74*
13 (8)	8.7t	0/1	4/11	16/17	2/2	4/4					4/4	.77*
14 (9)	10.0t	1/3	4/5	4/5	2/3	7/11	8/8	2/2			5/7	.75*
15 (10)	12.5t				0/1	4/10	10/13	10/12	4/4		4/4	.73*
Older Total		.25	.47	.82*	.71	.62	.89*	.91*	1.00		.75*	.79*
Both Ages		.20	.50	.80*	.68*	.70*	.88*	.85*	.62	.69	.76*	.75*

Note—The fraction shown for each individual child and disk size is the number of correct responses divided by the number of trials at that disk size. Proportions that were significantly above chance by a sign test for individual children (collapsed across disk size) and for specific disk sizes (collapsed across children) are indicated by asterisks. The subject numbers shown in parentheses are those from Experiment 1, to allow comparisons across experiments for the 10 children who participated in both experiments. Subjects with some history of formal orientation and mobility training are designated by a "t" following their age.

dren who did not perform above chance overall (22 of the 29 trials at these two disk sizes were done with such children), so the findings do not indicate how the other children would have done at those disk sizes. The findings for the 20-in. disk, presumably the easiest to discriminate, may have been deflated because of the psychophysical rules that were used. After two consecutive incorrect trials, the 20-in. disk was presented on the next trial, so it tended to be presented during portions of a session when the child's attention to the task may not have been optimal.

Discussion

The children were able to discriminate whether a disk was located to their right or left. Individually, 9 of the 15 children tested performed above chance level (5 of 6 older children and 4 of 9 younger children). Across individuals, performance was above chance level for 6 of the 10 disk sizes that were used (with chance level observed only for the two smallest disks and for two of the larger disks that happened to have been presented mostly to children who did not do well overall).

The children's discriminations were most likely based on auditory information. This claim is based on the absence of other sources of useful information and on findings—with adults—that auditory information is particularly useful in similar tasks (Rice, 1969). The children were blind and wore blindfolds to eliminate the use of residual amounts of light perception. The tests were conducted in a closed classroom free of noticeable air currents, odors, or temperature gradients. To assess the role

of audition, a blindfolded sighted adult was tested in a similar room with the 12-in. disk. She discriminated the side of presentation correctly on 25 of 30 trials (83%) with ears unoccluded but on only 16 of 30 trials (53%) with ears occluded by industrial ear protectors. The auditory information that the children could have used included reflected sound (from self-produced or ambient sound) and sound shadows cast by the disks. The children typically talked during the trial and nearly always turned their heads from side to side, which is consistent with the hypothesis that they were using auditory information.

GENERAL DISCUSSION

The findings in both experiments indicate that congenitally blind children aged 5 to 12 years can detect nearby objects without the use of any residual visual capacities. This ability was observed in a naturalistic locomotion task in Experiment 1 and in a forced-choice discrimination task in Experiment 2.

In most previous studies of nonvisual perception of objects at a distance, measures have been taken of adults making overt judgments about the presence and locations of obstacles. In particular, the early studies by Dallenbach and his group (e.g., Supa et al., 1944) established the paradigm in which subjects walked slowly toward an obstacle, stopping to report two perceptual experiences—the first perception of the obstacle, and the final appraisal, when they seemed so close to the object that to move any farther would cause them to contact it. This paradigm is well suited to investigations of adults concerning the in-

formation underlying nonvisual obstacle perception, since the distances at which first perception and final appraisal occur can be regarded as quantitative measures of perceptual ability. For example, Ammons et al. (1953) used these measures to show that auditory information was necessary and sufficient for what they called the obstacle sense. For investigation of some issues, however, these traditional measures are less well suited. In the present study, measures were sought that would be feasible with young children and that would indicate whether and how nonvisual obstacle perception is used in the context of ordinary situations. The approach was to carefully observe children as they engaged in the routine task of walking along a course with obstacles (Experiment 1) and to test them in a more constrained task calling for left/right discrimination of object positions (Experiment 2). The findings in both experiments confirm that children's nonvisual obstacle perception can be measured empirically. Moreover, this perceptual ability is manifested in functionally important behavior, such as goal-directed locomotion and awareness of the positions of objects in nearby space. This emphasis on nonvisual obstacle perception as a useful skill has received little attention in the experimental literature on adults (Strelow & Brabyn, 1982), yet an appreciation of the functional context of the ability may be necessary not only as a pragmatic basis for devising workable dependent variables but also as a theoretical rationale for exploring developmental influences.

In situations requiring mobility without vision, people must rely on other sensory modalities and on aids such as the long cane. The present experiments were not designed to isolate the specific nonvisual information mediating the children's detection of objects, but they were conducted under the assumption that auditory information would be the most useful. This assumption was based on clinical practice in orientation and mobility training (Welsh & Blasch, 1980), on experimental reports that nonvisual obstacle perception is at chance level when people are deprived of hearing (Ammons et al., 1953; Cotzin & Dallenbach, 1950; Strelow & Brabyn, 1982; Worchel & Dallenbach, 1947), and on numerous reports that obstacle perception is enhanced by auditory sensory aids such as directional noise generators (e.g., Clarke, Pick, & Wilson, 1975; Juurmaa, 1970). Efforts were made to minimize the potential contributions of nonauditory information such as wind (obstacles were downwind from the path of locomotion), heat and light shadows (the path was in full sunlight with the sun to the children's backs), and smell (the obstacles were placed downwind and did not have a strong odor). These arrangements, together with those in the studies on the contributions of audition just cited, lead us to believe that the children were detecting objects principally by means of auditory information.

The children had available to them natural sound information such as that provided by their own footsteps as well as by the ambient acoustic environment (e.g., sound shadows). There may be many specific sound cues and related psychological processes that underlie percep-

tion of a spatial layout. (Of course, localizing objects that are *sources* of sound is important, but the emphasis here is on spatial features other than sound-producing ones.) These cues would include, for example, the reverberant structure of the sound field as an indication of the size of a room, the characteristics of reflected sound as an indication of the distance of a surface, and the occurrence of local variations in ambient noise level as sound reflects from objects or passes through openings. This aspect of psychoacoustics is not yet well understood, although some specific models have been proposed (see Wilson, 1966, and Bassett & Eastmond, 1964, regarding apparent pitch changes resulting from sound wave interference patterns during approach to a reflective surface; see also Hartmann, 1983, for a consideration of room acoustics). It is interesting to consider how specific sound parameters and familiarity with certain sounds contribute to obstacle perception. For example, Schenkman and Jansson (1986) found that blind subjects were only moderately good at using long-cane tapping sounds to avoid panels placed in a pathway (there were collisions on 45% of trials), but a subject who insisted on using self-produced vocalizations was essentially perfect at avoiding the obstacles. Despite the theoretical and practical importance of understanding the auditory basis of obstacle perception, little research has been reported. For example, although it seems likely that pitch changes would be more useful for perceiving approach to a large surface such as a wall, and that intensity changes would be more useful for perceiving an opening such as a doorway, the contributions of different kinds of information have not to our knowledge been systematically studied. The present findings suggest that congenitally blind children utilize at least some of this auditory spatial information, and, moreover, that they coordinate the information with functionally important behavior such as goal-directed locomotion.

The finding that nonvisual perception of objects at a distance occurred in a group of congenitally blind children has implications for our understanding of the role of experience in the development of this ability. Concerning the role of visual experience, this study is consistent with previous reports that congenitally blind adults are capable of nonvisual obstacle perception, and it is the first demonstration that the ability is present in young congenitally blind children. Despite the clinical impressions of orientation and mobility instructors that congenitally blind people can use this auditory information, we know of only a few systematic demonstrations, with the following numbers of congenitally blind adult subjects: Juurmaa (1970), 1; Rice (1969), 6; Strelow and Brabyn (1982), 6; and Worchel et al., (1950), 18 (although Worchel et al. did report findings for their total sample of 34 subjects, including 16 who had normal vision early in their lives). Evidence of the ability in congenitally blind people rules out the possibility that visual experience is necessary for its development—that vision plays an exclusive inductive role. Evidence of the ability in young congenitally blind children, including those with little or no formal orienta-

tion and mobility training, suggests further that the auditory information is utilized fairly spontaneously during early development. This is consistent with Rice's (1969) finding that adults with early onset of visual impairment (before 6 months) were superior to those with later onset and to sighted adults at detecting and localizing small disks.

The children in the present experiments were chosen as a group with minimal early visual experience or formal training experience. We cannot rule out that they may have had some useful vision during early infancy, that their minimal visual capacities may have contributed during development to nonvisual obstacle detection, or that their natural experience in getting around in various environments even without formal mobility instruction may have helped them. However, this study provides positive evidence of an important nonvisual spatial ability that seems to develop with minimal visual experience or formal training. Many questions of theoretical and practical importance about the conditions supporting nonvisual obstacle perception remain to be investigated. It would be interesting to monitor changes during the course of formal training experiences and to compare obstacle perception across groups varying in degree and developmental time of onset of visual impairment. It is also important that the specific auditory information underlying obstacle perception be elucidated. The present findings indicate that young visually impaired children use this information even without systematic training, which provides an incentive for understanding the processes more fully and applying this knowledge to intervention efforts.

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