Abstract: Curb ramps, which are necessary to enable some persons with physical disabilities to negotiate street crossings, appear to put persons with visual impairments at risk. In 39 percent of 557 approaches to unfamiliar streets via curb ramps, persons who travel using a long cane were unable to detect the streets and to stop before entering them. Street detection was highly associated with the angle of the slope, the abruptness of the change from the approaching sidewalk to the curb ramp, and the location of curb ramps.

As legislation guaranteeing environmental access to persons with disabilities is enacted and modifications are made, curb ramps are being installed at intersections throughout the country to ensure access for persons who cannot negotiate curbs. However, the primary cue indicating that persons who are blind have reached a street has traditionally been the presence of a down curb (Allen, Griffith, & Shaw, 1977; Hill & Ponder, 1976). Concern that curb ramps would create hazards for blind pedestrians led the American National Standards Institute (ANSI) (1980, 1986) to require warnings on curb ramps that would provide a cue detectable to blind travelers, so they could differentiate the curb ramps from the preceding sidewalks and streets.

Continuing concern that the presence of curb ramps impairs the ability of persons who are blind to detect and safely cross streets resulted in requirements for detectable warnings on curb ramps in the Americans with Disabilities Act Accessibility Guidelines (ADAAG)(1991):

- 4.7.4. Detectable Warnings. A curb ramp shall have a detectable warning complying with 4.29.2. The detectable warning shall extend the full width and depth of the curb ramp.
- 4.29.2. Detectable Warnings on Walking Surfaces. Detectable warnings shall consist of raised truncated domes with a diameter of nominal 0.9 in (23 mm), a height of nominal 0.2 in (5 mm) and a center-to-center spacing of nominal 2.35 in (60 mm) and shall contrast visually with adjoining surfaces, either light-on-dark or dark-on-light.

However, doubts about whether curb ramps do, in fact, pose problems for persons who are blind, coupled with concerns about the safety and negotiability of detectable warnings, particularly on sloping surfaces, for persons with physical disabilities, led to the temporary suspension of ADAAG requirements for detectable warnings on curb ramps until July 26, 1996, pending research (Federal Register, 1994).

Laboratory research by Bentzen, Nolin, Easton, Desmarais, and Mitchell (1994), which was confirmed in postconstruction evaluation research sponsored by the Architectural Transportation Barriers Compliance Board (see Hauger, Safewright, Rigby, & McAuley, 1994), indicated that detectable warnings on slopes, such as curb ramps, present minimal difficulties to persons with physical disabilities and that, in some situations, traction and safety are perceived to be greater on ramps with detectable warnings than on comparable brushed concrete ramps.

The research reported here was a first step in obtaining data on the effects of curb ramps on the ability of blind travelers to detect streets. Both human performance data (stopping before entering streets) and subjective data (cues that blind participants reported using to enable them to identify each street and the special techniques they were observed to use as they approached the streets) were obtained for 10 street approaches with curb ramps in each of eight cities. The street approaches varied in the slope, character of the approach, surface friction, location, and abruptness of curb ramps, and the location of curb ramps.

This article reports the results related to street detection and safety. The results regarding the cues that blind participants reported using to help them identify each street and the special techniques they were observed to use as they approached the streets are reported in Barlow and Bentzen (1994).

The research focused on the detection of streets because the inability to do so is the primary problem that persons who are blind report having as a result of curb ramps. In addition, street detection could readily be measured by asking participants to stop before they step into streets, a safety procedure routinely used by blind (as well as sighted) pedestrians to facilitate the receipt of information about traffic conditions (Allen et al., 1977; Hill & Ponder, 1976).

The following hypotheses guided the research:

* Persons with little or no vision who travel using a long cane will sometimes be unable to detect the presence of a street, when they approach it via a curb ramp.
* When there is traffic on the street to be detected, blind travelers will be likely to detect the street.
* Blind travelers will be more likely to detect streets approached via ramps that are more steep than ramps that are less steep.
* When the change in the slope from an approaching sidewalk to a curb ramp is abrupt, blind travelers will be more likely to detect streets than when the change is gradual.

The following hypotheses guided the research:
* When curb ramps are located diagonally on corners, blind travelers will be more likely to detect streets than when curb ramps are parallel to their paths of travel.

* Frequent travelers will be more likely to detect streets than will infrequent travelers.

* More proficient travelers will be more likely to detect streets than less proficient travelers.

Method

In each of the eight U.S. cities, a consultant orientation and mobility (O&M) specialist selected a route, recruited 10 participants, and collected data as the participants traveled the route, all according to a protocol and a videotape of a test of one participant provided by the principal investigators. The cities were Kalamazoo, MI; Atlanta; Silver Spring, MD; Austin, TX; Manchester, NH; Sacramento, CA; Amityville, NY; and Chicago.

PARTICIPANTS

The 80 participants (50 male and 30 female) had vision no better than light projection, used a long cane as their primary travel aid, and were willing and able to travel an unfamiliar route, at least occasionally. They ranged in age from 14 to 91, with a mean age of 39.5 years. The age of onset of the vision loss and the cause of vision loss varied, but 21 were congenitally blind and 59 were adventitiously blind. The primary causes of blindness were retinopathy of prematurity (14), glaucoma (13), trauma (12), and retinitis pigmentosa (10). Other causes of blindness were represented in smaller numbers. Four participants with retinitis pigmentosa had vision better than light projection in daylight or well-lit situations, but traveled the experimental route at night, when their vision was functionally “light projection.”

Fifteen of the participants had some, type of hearing loss, ranging from slight to pro-found, including three who were profoundly deaf, and three had some neuropathy. Two-thirds of the participants were frequent travelers, traveling six or more times a week; 12.5 percent traveled three or four times a week, and 20 percent traveled fewer than three times a week.

The participants were asked to rate their travel proficiency subjectively as excellent, good, fair, or poor. In addition, the consulting O&M specialists rated the participants’ travel proficiency using the same scale, basing it on their observations of the participants’ travel for a distance of about one block before the experimental route. The particular factors they observed included the width of the cane arc in relation to the width of the body, the height of the cane arc, the cane being in step (on the side opposite the forward foot), and the cane arc being well centered.

According to both the consultants’ evaluations and the participants’ self-reports, 75 percent of the participants were rated as good to excellent travelers; the others were fair travelers, and only one person was rated by a consultant as a poor traveler. All but one of the participants reported having had instruction in traveling using a long cane.

The participants’ travel speed was categorized by the consultants as fast, moderate, or slow on the basis of observations of the participants’ travel for a distance of one block before the experimental route. There were 22 fast travelers, 44 moderate travelers, and 14 slow travelers.

Routes

Each route included 10 street approaches that had curb ramps or blended curbs, including, as much as was possible in each city, various combinations of types of ramps and approaches to ramps. All the experimental ramps were approached from a straight travel direction of at least 50 feet. Figure 1 shows a typical route. Table 1 presents the characteristics of the curb ramps.

Procedure

The consultant O&M specialists followed procedures described in a written protocol, demonstrated on a videotape pro-vided by the principal investigators and reviewed at length by the second author. The participants were asked to travel independently, using their usual techniques, to each street along the experimental route and to stop when they determined that their next step would be in a street.

If the participants stopped within two feet of a street, the consultants recorded information about their approach to the street and about traffic conditions. Then the participants were asked to say what cues enabled them to detect the street. Following the data collection, the participants were guided across each street to a starting point at a random distance from the next street on the experimental route.

If the participants stopped and reported that they had arrived at a street and they were more than two feet from an intersecting street, they were told, “That’s not the street” and continued traveling until they again determined that they had arrived at a street.

Particular care was taken to control any behavior of the consulting O&M specialists that might indicate the participants’ location in relation to intersecting streets and thus might influence their stopping behavior. The consultants were trained in unobtrusive and noninfluential observation techniques through a videotape and subsequent debriefing by the second author. They maintained approximately the same distance from each participant at all times, unless they needed to intervene for safety. If the consultants had systematically been closer to the participants at times of potential risk (such as when nearing streets) than when there were less risk and the participants used the consultants’ behavior to anticipate their approach to streets, the result would have been a low incidence of failure to detect streets, which did not occur (see Results).

The consultants intervened verbally or physically, if necessary, for the participants’ safety at any point on a route, following the common practice of certified O&M specialists. (A more detailed description of the protocol is presented in Barlow & Bentzen, 1994).

Results and discussion

NATURE OF THE APPROACH

Of the 800 street approaches, the participants walked down the center of the curb ramp in 57 instances (see Table 2). On 118 approaches, the participants arrived at a downcurb, having made no contact with the curb ramp. On 52 approaches, the participants contacted and identified the curb ramp and then attempted to detour around it, so they would arrive at a downcurb. The 68 approaches that were grouped as “other” included walking down the side of the ramp or walking diagonally down the ramp, so that, in either case, contact was made with the (steeper) flare of the ramp and there was some raised curbing where the participants reached the street. Five of the 800 approaches are not tabulated...
because the O&M consultants thought that the participants might have misunderstood the instructions. In four of the five cases, the participants stopped four or five feet from the street. Following the research protocol, the consultants told the participants, "That's not the street," and the participants resumed walking, assuming they were not near the street, and entered the street. In the other case, the participant traveled around the corner without approaching the intended intersection; the approach was not rerun, and no score was possible.

Of the 557 approaches in which the participants walked down the curb ramp, they stepped into the street on 197 approaches (35%) (see Table 2). (Additional information on the distances that the participants traveled into the street is presented in Barlow & Bentzen, 1994.)

In addition, the consultants recorded 149 false-positive scores, indicating that the participants stopped and thought they were at a street when they were not. This finding may be indicative of the level of uncertainty with which blind persons travel in unfamiliar areas.

**PERPENDICULAR TRAFFIC CONDITION**

It was anticipated that one of the most powerful cues to the presence of a street would be the presence of traffic, either moving or idling, and that when there was traffic on the perpendicular street on the participant's line of travel—the one that the participant would cross if he or she continued straight ahead—there would be a few instances of stepping into the street. However, for street approaches in the center of the ramp, 239 approaches, in which there was moving perpendicular traffic, resulted in 75 instances (31%) of inadvertent street entry, and 114 approaches with idling perpendicular traffic resulted in 41 instances (36%) of inadvertent street entry. Thus, in these two conditions, there were 116 instances (or 59% of the 197 instances of inadvertent street entry) of stepping into a street in which there was traffic.

To understand further the nature of the relationship between the presence of perpendicular traffic and the ability of blind travelers to stop when they come to streets, a chi-square analysis of stopping frequency x perpendicular traffic condition was performed; the finding was not significant (x²=3.35, p>0.05). A further 2 x 2 chi-square analysis was conducted just between the two conditions in which perpendicular traffic was present (moving versus idling); this finding was also not significant (x²=.74, p>.05). Therefore, despite the frequently reported use of traffic as an indicator of the location of a street, there appears to be no statistically significant relationship between the actual presence of traffic (moving or idling) and the ability of persons who are blind to detect streets and stop before entering them.

**NATURE OF CURB RAMPS**

**Slope**

The curb ramps included in the study varied in slope from 0 degrees to 13 degrees. Eleven ramps had slopes of 5 degrees, which includes slopes from 1:11 to 1:13. Thirty-eight had slopes of 4 degrees or less (equal to less than 1:14). Thirty-one had slopes of 6 degrees or more (greater than 1:10)—steeper than is permitted in new construction for most curb ramps (ADAAG, 1991). It was hypothesized that blind travelers would be more likely to detect streets when approaching from the steeper ramps.

For slopes of 4 degrees or less, there was a 51 percent rate of entering the street; for slopes equal to 5 degrees, there was a 30 percent rate of entry; and even for the steepest slopes (of 6 degrees or more), there was an 11 percent rate of entry.

A chi-square analysis of stopping frequency x slope was highly significant (x²=82.83, p<0.01). Additional 2 x 2 chi-square analysis revealed that stopping frequencies for slopes of 6 degrees or more versus slopes of 5 degrees were significantly different (x²=9.47, p<0.01), as were the stopping frequencies for slopes of 5 degrees versus those of 4 degrees or less (x²=6.99, p<0.01). Therefore, persons who are blind are much more likely to detect a street and to stop without entering it when the ramp is steep. However, even on the steepest curb ramps permitted in the new construction (5 degrees), the rate of failure to stop was 30 percent. For the 49 ramps with slopes of 1:11 or less (5 degrees or less), there were 363 approaches in which the participants traveled down the center of the curb ramp. Of these 363 approaches, the participants entered the street on 175 approaches (48%).

**Rate of change in the slope**

The rate of change in the slope between the approach to each curb ramp and the ramp itself was subjectively judged by the consultant in each city as either "abrupt" or "gradual." It was hypothesized that encountering an abrupt change in a slope, regardless of the slope of the curb ramp, would be a good cue that the junction between ramp and street was nearby and, therefore, that the stopping rates for approaches with abrupt changes would be higher than for approaches with gradual changes.

On the 413 approaches to ramps that changed gradually, the participants entered the street 176 times (43%), whereas on the 144 approaches to ramps that changed abruptly, the participants entered the street 21 times (only 15%).

A 2 x 2 chi-square analysis of stopping frequency x rate of change was highly significant (x²=36.67, p<0.01). Thus, an abrupt rate of change facilitates street detection from a curb ramp.

**Parallel versus diagonal ramps**

It was hypothesized that diagonal ramps might lead to greater detection than would parallel ramps because the cross slope and the angle of the ramps would require blind travelers to turn in order to walk directly down the ramp. On the 413 approaches to parallel ramps, the participants entered the street 163 times (39%), whereas on the 138 approaches to diagonal ramps, the participants entered the street only 34 times (25%).

A 2 x 2 chi-square analysis of stopping frequency x ramp location (parallel versus diagonal) was highly significant. (x²=9.24, p<0.01). Therefore, when travelers who are blind approach a street by walking down a diagonal curb ramp, they are more likely to stop without inadvertently stepping into the street than when they approach a street by traveling down a parallel ramp. Nonetheless, on 25 percent of the approaches via diagonal ramps, the participants entered the street. Persons who are blind and who walk directly down diagonal curb ramps and out into streets are at a considerable risk because they are then usually headed into the middle of intersections, where they are likely to be in the path of travel of vehicles on both streets.

**Additional observations**

Of the 80 approaches, 14 were detected by all the participants; 12 of the 14 had curb ramps with slopes of 5 degrees or more and often much steeper than 5 degrees. The steepness of the slope of the curb ramp was the main common characteristic of these street approaches.

The 10 most difficult-to-detect streets, where most participants who traveled down the ramp stepped into the street, had ramps with a slope of 4 degrees or less, and at least one of the following additional characteristics: curb ramp parallel to the traveler's path, a quiet street or busy street...
with surges of traffic and/or gaps in traffic, no building line or a building line that was different from others on the route, little or no change in texture or upslope (crowning) at the street, and/or a change that was considered gradual. Five of these 10 most difficult approaches had no building line or a building line that varied from others on the route.

Two streets were inadvertently entered by every traveler who approached them. One was a quiet residential street, with bushes along the inside shoreline, a gradual slope, and a slight change in texture at the street. The other had a 0 degrees ramp slope following an uphill slope, approaching five lanes of one-way, heavy and fast-moving, but intermittent traffic.

FREQUENCY OF TRAVEL

It was hypothesized that blind persons who travel frequently would be less likely to enter streets inadvertently when traveling down curb ramps than would those who travel infrequently. The participants reported their frequency of independent travel in trips per week: at least five trips, three or four trips, or fewer than three trips.

On the 392 approaches made by participants who traveled independently at least five times a week, the participants entered the street 132 times (34%). On the 63 approaches made by participants who traveled three or four times a week, the participants entered the street 26 times (41%); and on the 102 approaches made by the participants who traveled fewer than three times a week, the participants entered the street 39 times (38%). A chi-square 2 x 3 analysis of stopping frequency x travel frequency was not significant (x²=1.82, p>.05). Thus, infrequent travelers are just as likely to step into streets inadvertently as are frequent travelers.

PROFICIENCY IN TRAVEL

The consultants' evaluations of the participants' proficiency in travel were based on observations of short and straight travel distances, which did not give the consultants the opportunity to evaluate the participants' spatial problem-solving ability. The evaluations were based on observations of the participants' traveling only short distances, and these observations indicated little about the participants' spatial thinking, which spatial problem-solving could be a better predictor of the ability to detect streets than are cane techniques, which were the primary basis for the consultants' ratings. The participants' own ratings of their proficiency were expected to be much more comprehensive and hence to provide some correction to the consultants' ratings. However, the participants' ratings of travel proficiency were positively correlated (Spearman's rho) with the consultants' ratings (rs=.355, p<.01), based on the ratings of 78 participants (the ratings of two participants were missing). The consultants' ratings were normally within one step of the participants' ratings.

On the 409 approaches made by the "excellent-good" travelers, the participants entered the street 135 times (33%), while on the 148 approaches made by "fair-poor" travelers, the participants entered the street 62 times (42%). A 2 x 2 chi-square analysis of stopping frequency x travel proficiency was significant (x²=3.75, p<.10). Thus, persons with good-excellent skills were somewhat more likely to detect the street than were persons with fair-poor skills.

Of 12 participants who never inadvertently entered the street, 10 were rated as "good" or "excellent" travelers and two were rated as "fair," by both the participants and the consultants. Other characteristics shared by these participants were a relatively fast walking pace and their reports that they noticed multiple cues to the presence of streets.

OTHER VARIABLES

Additional independent variables were analyzed and reported in Barlow and Bentzen (1994). Persons who traveled rapidly appeared to be more likely to detect streets than did those who traveled more slowly. Their cane technique (the touch technique versus the constant-contact technique), cane length, and impaired hearing did not appear to influence their detection of streets.

Cues that the participants reported using to enable them to detect streets, as well as the techniques observed by the data collectors, are also discussed by Barlow and Bentzen (1994). Of the 22 cues reported, the most frequently mentioned were the slope of ramps and the presence of perpendicular traffic.

Conclusions

Advocacy by persons with visual impairments and their service providers led to the adoption of requirements by ANSI (1986) and by the Architectural and Transportation Barriers Compliance Board (ADAAG, 1991) for detectable warnings on curb ramps. Advocates were concerned that although curb ramps are necessary for persons with some disabilities, they may impair the safety of persons who are blind by removing a primary cue to the presence of a street. At that time, there were no data to indicate whether this concern was warranted.

The research presented here found that curb ramps do, in fact, affect the safety of individuals with visual impairments. In 39 percent of street approaches via curb ramps, the participants were unable to recognize the presence of a street and to stop before entering it.

Streets were harder to detect when approached via ramps with minimal slopes than via steeper ramps. For ramps complying with ADAAG (1991) (having slopes of 1:12 or less), the participants failed to stop on 48 percent of the approaches. An abrupt change in slope between an approaching sidewalk and a curb ramp appears to facilitate the detection of streets. Curb ramps that are located diagonally on corners also seem to facilitate street detection, but they may be associated with disorientation.

The inability to detect a street and to be able to come to a stop before entering it places individuals who are blind at particular risk if there is traffic on the street. In 59 percent of the approaches on which the participants continued into the street, there was traffic.

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Table 1

Characteristics of curb ramps.
Legend of Chart
A - Site
B - Ramp location[a], Parallel
C - Ramp location[a], Diagonal
D - Rate of change[b], Gradual
E - Rate of change[b], Abrupt
F - Angle of slope[c], \(<=4\) degrees
G - Angle of slope[c], 5 degrees
H - Angle of slope[c], \(>=6\) degrees

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a Parallel to participant's direction of travel, or participant headed diagonally into the intersection.
b Rate of change from the approach to the curb ramp, to the curb ramp itself, subjectively judged by consultants as gradual or abrupt.
c The slope of the ramp was measured by an angle protractor accurate to 1 degree. A 5 degrees slope is equal to 1:11-1:13.

Table 2
Stopping frequency by nature of participants' approach
(number of approaches; percentages in parentheses).

Legend of Chart:
A - Type of approach to street
B - Approaches on which participants stopped before stepping into the street without stepping into the street
C - Approaches on which participants stepped into the street without stopping
D - Total

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<td>104 (88)</td>
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<td>Avoided ramp</td>
<td>45 (85.5)</td>
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<td>60 (88)</td>
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<td>226 (28)</td>
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* Five of the 800 approaches were not counted because of procedural irregularities.

DIAGRAM: Figure 1. Prototypical experimental route.

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