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Tactile Warnings to Promote Safety in the Vicinity of Transit Platform Edges

U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142-1093

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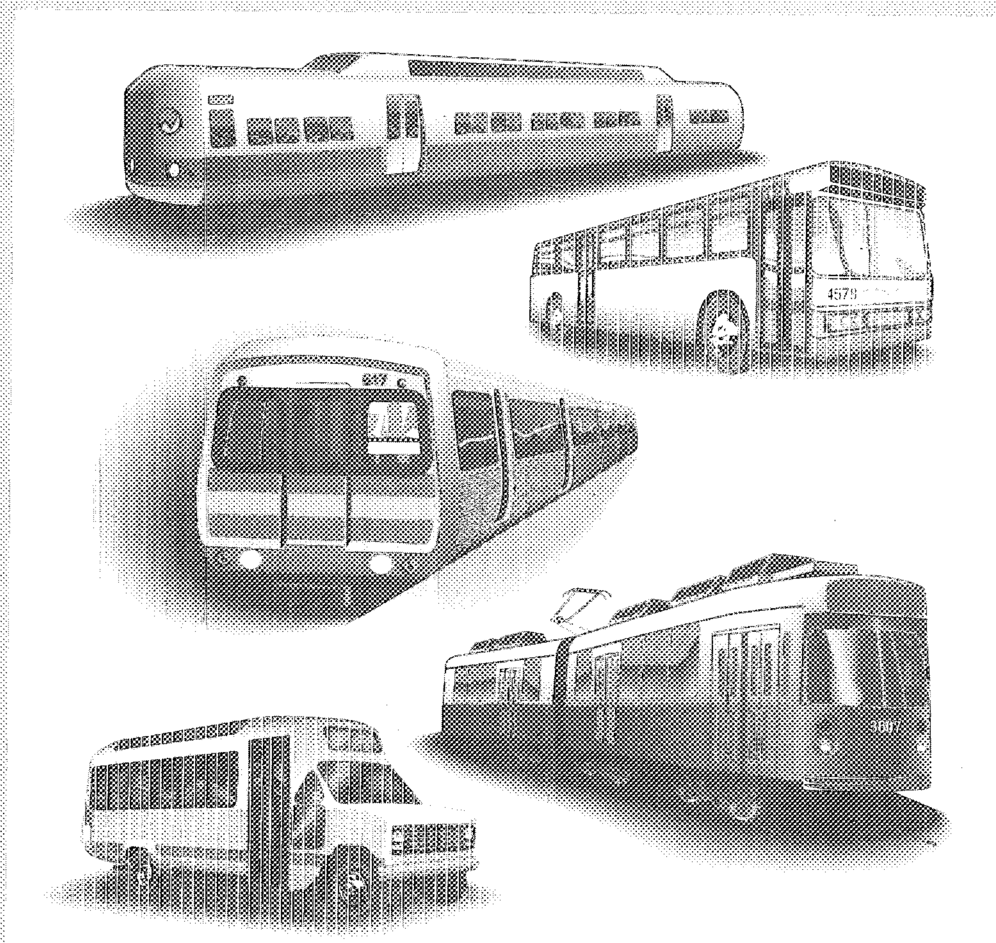

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13. ABSTRACT (Maximum 200 words)

Concern for the safety of visually impaired individuals at the platform edge in rail rapid transit stations led to this study of potential tactile warnings which are designed to give the visually impaired traveler an underfoot warning as the edge is approached.

The report describes three related studies:

1. initial laboratory research to identify potential tactile warning materials, in which 23 blind travelers using long canes or guide dogs attempted to locate each of four distinct edge warning materials which were contrasted with four different base platform materials;

2. in-transit research at BART in San Francisco, in which three different edge warning materials in four stations having different environmental characteristics were experimentally tested on 30 totally blind subjects (with an additional study of the effect of the materials on the travel of 24 ambulatory-impaired travelers); and

3) a follow-up laboratory study of "Pathfinder Warning Tiles," which were introduced into the BART study and appeared to have useful warning properties.

Evaluations of the materials and recommendations for installation in rail transit stations are included.

14. SUBJECT TERMS
Tactile Warnings, Platform Edge, Blind, Visually Impaired, Rail Rapid Transit, Pathfinder Warning Tile

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PREFACE

The possibility of falling from the edge of a rail rapid transit platform onto the track bed below is a major concern to visually impaired travellers when using rail rapid transit stations. This document presents the results of a project to address this concern through the use of tactile warning materials to assist visually impaired travellers in detecting the station platform edge. Presented in three sections, the report documents: the results of laboratory research on the basic tactile warning concept, an evaluation of in-transit service, and an additional laboratory evaluation of two types of tactile warning systems.

Section 3, prepared by Billie Louise Bentzen, was funded by the Urban Mass Transportation Administration (UMTA) Office of Methods and Support, Analysis Division. The authors wish to thank and acknowledge Ross W. Adams, Chief of the Analysis Division, for his support and guidance in the formulation and implementation of this project.

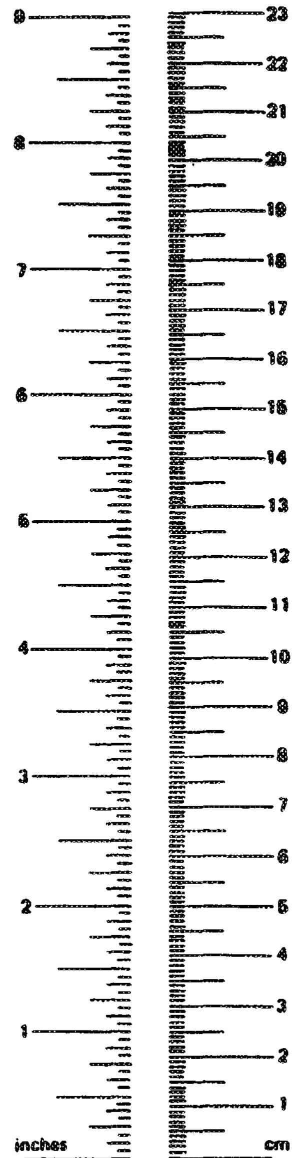
Sections 4 and 5, prepared jointly by Billie Louise Bentzen and Alec F. Peck, were funded by the UMTA Office of Safety and Security through the safety program sponsored by UMTA at the Transportation Systems Center (TSC). The authors wish to acknowledge the contributions of Steven A. Barsony, Acting Director of Safety and Security, and the staff of the Office of Safety and Security for their support and guidance to this project. The editorial assistance of Karen C. Cubie of Dynatrend, Inc. was greatly appreciated. Finally, the authors would like to acknowledge William T. Hathaway of TSC for his assistance in carrying out the research for sections 3 and 4 and in the publication of this report.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

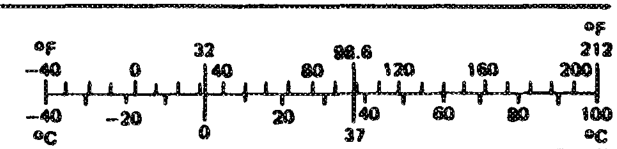
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 INTRODUCTION

A major safety concern for visually impaired travellers on rail rapid transit is the possibility of falling from a high platform onto the track bed (Bentzen, Jackson and Peck, 1981). Although data on the frequency of such falls is difficult to obtain, some information is available which indicates that visually impaired travellers are at much greater risk than normally sighted travellers. Totally blind travellers have tools and techniques to detect a platform edge before stepping off, but these tools and techniques are not always adequate for preventing falls. Both travellers using long canes and those using dog guides have fallen; a majority have been injured, some seriously (Crawford, 1987; Weule, 1987). In a majority of falls reported in one city, the blind traveller was a frequent user of rail rapid transit and of the station in which the fall occurred (Crawford, 1987).

In the first ten years of operation of BART (San Francisco) one third of all falls to the trackbed which were observed or reported to BART personnel occurred to visually impaired travellers (Weuele, 1987). An informal consumer-focused survey conducted in the Boston area during March and April 1987 identified 23 such incidents (Crawford, 1987). Of 20 respondents who offered information about injury, 100% experienced some level of injury, and 21% experienced injuries resulting in permanent additional disability. It is interesting to note that in 76% of the incidents reported, respondents were frequent users of rail rapid transit .

This document presents the results of a project to address this concern through the use of tactile warning materials to assist visually impaired travellers in detecting the station platform edge. Presented in five sections, the report documents:

1. The results of laboratory research on the basic tactile warning concept;
2. An evaluation of in-transit service; and
3. An additional laboratory evaluation of two types of tactile warning systems.

2.0 PREVIOUS TACTILE WARNING RESEARCH

2.1 EARLY RESEARCH

2.1.1 Aiello and Steinfeld - Concern about the danger to visually impaired travellers inherent in any sudden downward level change, led Aiello and Steinfeld (1980) to consider the possible utility of a tactile warning preceding any level change. In an experiment with eight visually impaired travellers using long canes for travel aids, the detection rates were compared for two warning materials, applied in two configurations, all applied to a concrete interior floor. Materials tested were: an abrasive material raised 1/64 inch, 1/32 inch, or 1/8 inch above the floor applied either in strips or a solid area; and ribbed rubber matting, applied either in two six inch wide strips, or in a solid area. When detection rates for abrasive strips of different heights were compared, it was found that at 1/64 inch no-one sensed the signal; at 1/32 inch the signal detection rate was 72%; and at 1/8 inch the signal detection rate was 83%. The solid area of ribbed rubber mat (five feet by five feet) was detected in 100% of approaches by all subjects, regardless of cane technique used. In some approaches, subjects reported sensing the mat first with the cane; in other approaches, the mat was reported to have first been detected under foot. The mat was detected equally well regardless of the direction of the ribbing, (i.e. parallel or perpendicular to a subject's line of travel). All subjects preferred the large mat above both the abrasive surfaces and the strips of rubber mat because of the size and the changes in texture, resiliency and sound.

The results of Aiello and Steinfeld (1980) were the basis for the following ANSI A117.1-1980 Standards:

> 4.29 Tactile Warnings
>
> 4.29.1 General. If tactile warnings are required, they shall comply with 4.29.
>
> 4.29.2 Tactile Warnings on Walking Surfaces. Tactile warning textures on walking surfaces shall consist of exposed aggregate concrete, rubber, or plastic cushioned surfaces, raised strips, or grooves. Textures shall contrast with that of the surrounding surface. Grooves may be used indoors only.
>
> 4.29.4 Tactile Warnings at Stairs. All stairs, except those in dwelling units, in enclosed stair towers, or set to the side of the path of travel, shall have a tactile warning at the top of stair runs.
>
> 4.29.5 Tactile Warnings at Hazardous Vehicular Areas. If a walk crosses or adjoins a frequently used vehicular way, and if there are no curbs, railings, or other elements detectable by a person who has a severe visual impairment separating the pedestrian and

vehicular areas, then the boundary between the areas shall be defined by a continuous 36 inch (915-mm) wide tactile warning texture complying with 4.29.2.

2.1.2 Templer and Wineman

Templer & Wineman (1980) studied the detectability of 11 materials when approached from broom finish concrete. Subjects were all legally blind -- totally blind, having low residual vision, or high residual vision. Only the results from totally blind subjects are presented here. Objective measures were detection of a material and stopping distance. In addition, blind subjects rated the ease of detection of the seven most objectively detectable materials. The materials tested are listed in Table 2-1. The following information is given for the materials: detection score; the distance within which 90% of subjects stopped (for the seven materials which were detected by at least 70% of subjects); and mean ratings for ease of detectability (based on a four point Likert scale where 1= very easy).

Templer & Wineman (1980) concluded by recommending that either a resilient material such as Kushionkote, a tennis court surfacing material, or strips of thermoplastic six inches wide, spaced six inches apart, and placed perpendicular to the normal line of travel be considered for detectable walkway surfaces; and that these surfaces should be at least 48 inches wide, allowing a 48 inch stopping distance.

2.2 SURFACE DETECTION AND TEXTURE PROJECT BACKGROUND

Further research was reported by Templer, Wineman and Zimring in 1982. This project attempted to determine the relationship between surface detection and texture (defined as depth, spacing, and width of grooves), impact noise, and rebound. Subjects in Templer & Wineman's previous study, as well as in that of Aiello and Steinfeld (1980), had reported that all of these factors contributed to their ability to detect surface changes; now it was hoped to quantify the contribution each of these factors made to detection, and to develop regression equations useful in predicting the probability that a particular surface (perhaps an untested one) would, in fact, be detectable. Conceptually, this is a valuable approach, and the investigators did succeed in arriving at regression equations useful where texture can be described in terms of groove width, spacing and depth; and where the contrasting surface is brushed concrete. Thirty-two potential warning surfaces tested in this study were combinations of concrete, plastic (thermoplastic, neoprene, and corrugated plastic), wood, and steel. Additional texture was added to some surfaces with paint. Textures were linear or non-linear (raised lines, circles or squares). Materials were installed over concrete or above a cavity (varying from 3/4 inch deep to 1 3/4 inches). All subjects used long canes as travel aids.

The regression equations of Templer et al. (1982) may be useful in choosing tactile

TABLE 2-1. DETECTABILITY OF 11 MATERIALS WHEN APPROACHED FROM BROOM FINISH CONCRETE (COMPILED FROM TEMPLER & WINEMAN, 1980)

MATERIALS	DETECTION RATING SCORE*	DISTANCE WITHIN WHICH 90% OF SUBJECTS STOPPED**	SUBJECTIVE EASE OF DETECTABILITY (MEAN RATING) ***
1. Thermoplastic solid	B		
2. Thermoplastic strips	A	42 inches	2.00
3. Ruled concrete	B		
4. Exposed aggregate	A	48 inches	1.28
5. (no texture - control)	-		
6. Kushionkote	A	42 inches	1.88
7. Pliant polymer	A	30 inches	2.44
8. Burlap finish concrete	C		
9. Paving brick	B	42 inches	2.01
10. Knicked concrete	A	42 inches	2.06

* A = Detected by at least 85% of subjects
B = Detected by at least 70% but less than 85% of subjects
C = Detected by less than 70% of subjects

** Includes only those materials detected by at least 85% of subjects. Distance is given to the nearest 6 inches.

*** Includes only those materials detected by at least 85% of subjects.

warnings reliably detectable by blind travellers using long canes, for use in combination with brushed concrete platforms. They would not be helpful in choosing warnings for use in combination with platform flooring materials which differed from brushed concrete in their texture, impact noise and rebound. A further difficulty in using the equations to choose appropriate warnings for the rail rapid transit environment is that impact noise was found to be the single most important predictor of detectability among the particular surfaces tested, and high ambient noise in this transit environment could mask the sound cues found to be so valuable in the quiet laboratory.

The actual rates of detection of various surfaces tested by Templer et al. (1982) were of interest to the principle investigators of this project because they suggested potential warning materials to be used in combination with other base surfaces.

Most importantly to this project, of a total of nine steel surfaces (varying in texture and in presence or absence of a cavity), five were detected on 100% of trials. Detection rates of the other four were 95% or better. The next best material was plywood to which various plastics or paint had been applied. Of the five surfaces subjectively rated easiest to detect (mean ratings), three were steel and two were plywood. Sound was subjectively considered to be a major factor in detection of these predominantly steel or plywood surfaces. Templer et al. (1982) concluded by highly recommending all nine of the steel surfaces, all seven surfaces for which plywood was the base or underbase, and three other surfaces in which concrete was the base material. The detection rate for each of these recommended surfaces was 95% or better. No one texture appeared better than any other.

Of those subjects who detected a warning surface, 86.4% stopped after traversing 24 inches or less of the surface. A 42 inch depth was necessary to insure stopping by virtually all subjects. Stopping distance could not be predicted on the basis of the surface used.

The state-of-the-art at the beginning of the project reported here was that several materials had been identified which had high rates of detectability by blind persons travelling with the aid of long canes, when these materials were used in combination with relatively smooth concrete. The most promising for use in a rail rapid transit environment appeared to be ribbed rubber matting, tennis court surfacing, and steel. A 42 inch - 48 inch warning seemed to be necessary to assure detection and stopping by virtually all subjects. No information was available on detection of warning materials in combination with basic flooring materials other than concrete. No information was available on detection of warnings by users of dog guides, and no information was available on detection of warnings after practice.

3.0 LABORATORY RESEARCH TO IDENTIFY POTENTIAL TACTILE WARNING MATERIALS

This project was designed to address the following questions of particular relevance to rail rapid transit.

1. Can a warning material which is highly detectable in combination with varied basic platform flooring materials be identified?
2. Can a warning material which is highly detectable by both cane and dog users be identified?
3. Does practice significantly alter the stopping distance in response to a warning surface?

3.1 SURFACE DETECTION AND TEXTURE PROJECT

3.1.1 Method

3.1.1.1 Subjects - Twenty-three blind travellers (totally blind or having no more vision than light perception) participated in this experiment. Of these, 13 customarily travel with only a long cane, four customarily travel with only a dog guide, and six travel with either a cane or dog guide. Of those who travel only with a long cane, eight completed the experimental procedure two times, giving performance data on both naive and practiced trials. Six subjects who travel with either a cane or dog guide also completed the experimental procedure two times, giving performance data for the same subjects using two different travel aids. (Half of these completed the procedure first with a cane, and half first completed it using dog.)

Subject characteristics are summarized in Table 3-1.

3.1.1.2 Materials - An experimental area was contructed which permitted subjects to travel from each of four examples of materials in common use as basic flooring surfaces for rail rapid transit platforms in the United States to each of four potential warning surfaces (See Fig. 3-1). The four basic platform surface materials were selected on the combined bases of common usage and extremes of texture, friction and density (resiliency). Information was requested from all authorities operating rail rapid transit systems in the United States on platform flooring materials in current use. Of the 12 materials in use, the four chosen for the experimental area were:

1. smooth concrete;
2. heavy wooden decking;
3. hard rubber tile with a pattern of raised circles (Pirelli Tile); and

TABLE 3-1. SUBJECT CHARACTERISTICS

AGE	MALE	FEMALE	USED CANE ON ONE TRIAL	USED CANE ON A SECOND TRIAL	USED DOG GUIDE
21	x		x	x	
26	x		x		
30	x		x		
30		x	x		x
30		x			x
30		x			x
31	x		x		x
31	x		x	x	
31		x			x
31		x	x	x	
31		x	x		
31		x	x		x
32		x	x		
32		x			x
32	x		x	x	
32	x		x	x	
33		x	x	x	
37		x	x		
38	x		x		x
40		x	x		x
40	x		x	x	
41	x		x	x	
61		x	x		x

Total of individual participants - 23
Total of trials - 37

*All subjects were totally blind or had no more than light perception.

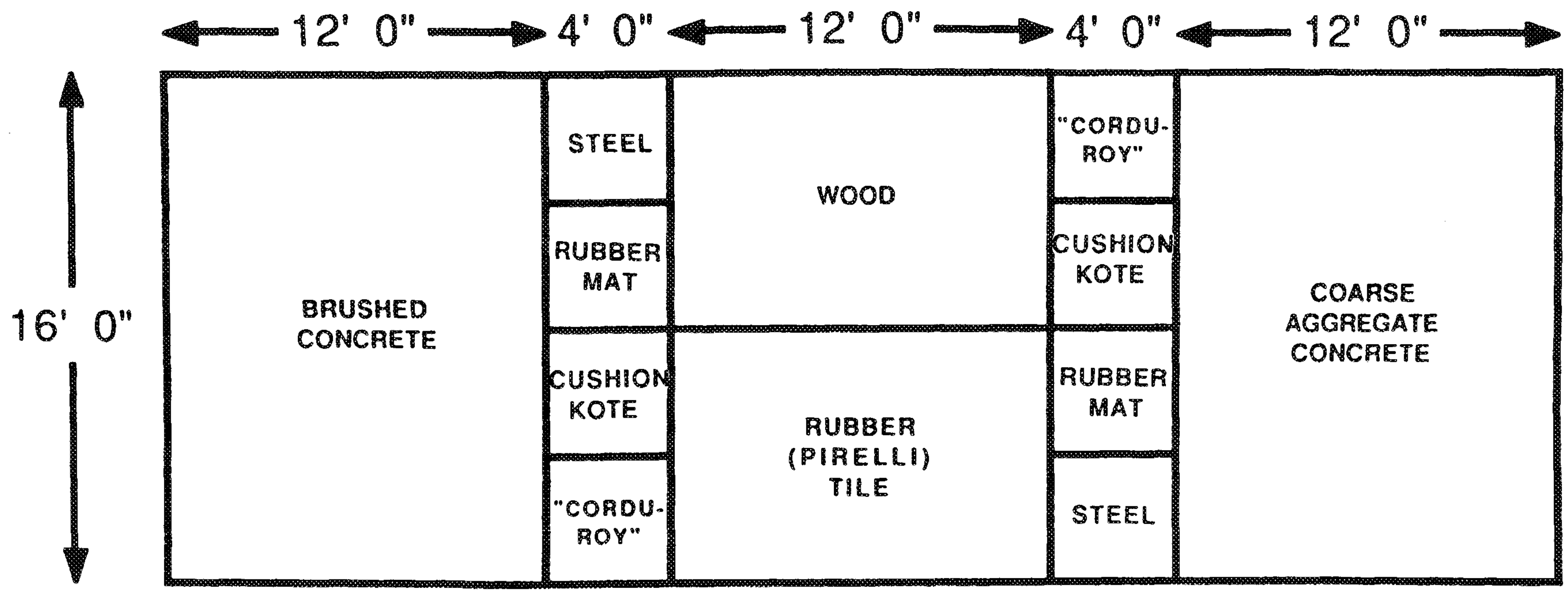


FIG. 3-1. LABORATORY TEST SITE

4. concrete with a coarse aggregate finish.

It was thought that if a warning material or materials could be identified which were reliably detected in conjunction with all four of these basic flooring materials, recommendations for tactile warning materials might not have to be based on consideration of the flooring material with which they were used. Instead, a warning material or materials might be recommended for standard use throughout all systems. Blind consumers have repeatedly stressed the importance of consistency in design both within systems and between systems.All types of information are most useful to visually impaired travellers when they are used in consistent location so that the traveller can rely on their existence and anticipate their locations.

The four potential warning materials were tennis court surfacing ("Cushionkote"), a rough steel plate, a ribbed rubber mat, and a hard "corduroy" pattern. The tennis court surfacing was chosen because of its excellent performance in the first set of experiments conducted by Templer & Wineman (1980).

The rough steel plate was chosen because of the excellent performance of all steel surfaces in Templer et al.'s second set of experiments (1982). There were two reasons for choosing a rough textured plate rather than one of the textures described by Templer et al. First, the rates of detection for the variously textured steel surfaces tested by Templer were nearly identical, so it is probable that subjects were responding to the change in material rather than any particular change in texture. Second, the literature on detection of texture differences by the fingertips indicates that relative roughness contributes more to detection of different textures than the shape of the elements making up the texture (Schiff & Levi 1966). A commercially available steel plate with a rough texture was therefore chosen to maximize slip resistance and to enhance detection even more than the various patterns investigated by Templer et al.

The ribbed rubber mat was selected because it differed greatly in density from all the basic platform flooring materials. It was thought that this difference in density as well as the ribs (which cause a slight horizontal displacement of the foot) would contribute to making this material detectible under foot. The mat was similar to the one found best by Aiello and Steinfeld (1980).

The "corduroy" surface was desired for testing because it was hypothesized that a linear pattern in which the lines were dome-shaped in cross-section would be more detectible under foot than a linear pattern in which the lines were flat-topped. A variety of linear patterns had been previously tested (Aiello & Steinfeld 1980; Templer & Wineman 1980; Templer, et al 1982) which were flat-topped. They are not notably detectable (See Fig.3- 2). The hypothesis that dome-shaped linear textures would be highly detectable was based on research on finger perception, specifically perception and legibility of braille, in which the optimal shape was found to be half-spherical or somewhat conical (Burklen, 1932). No commercially available product having the desired dimensions and contours could be located; therefore, a prototype surface was constructed

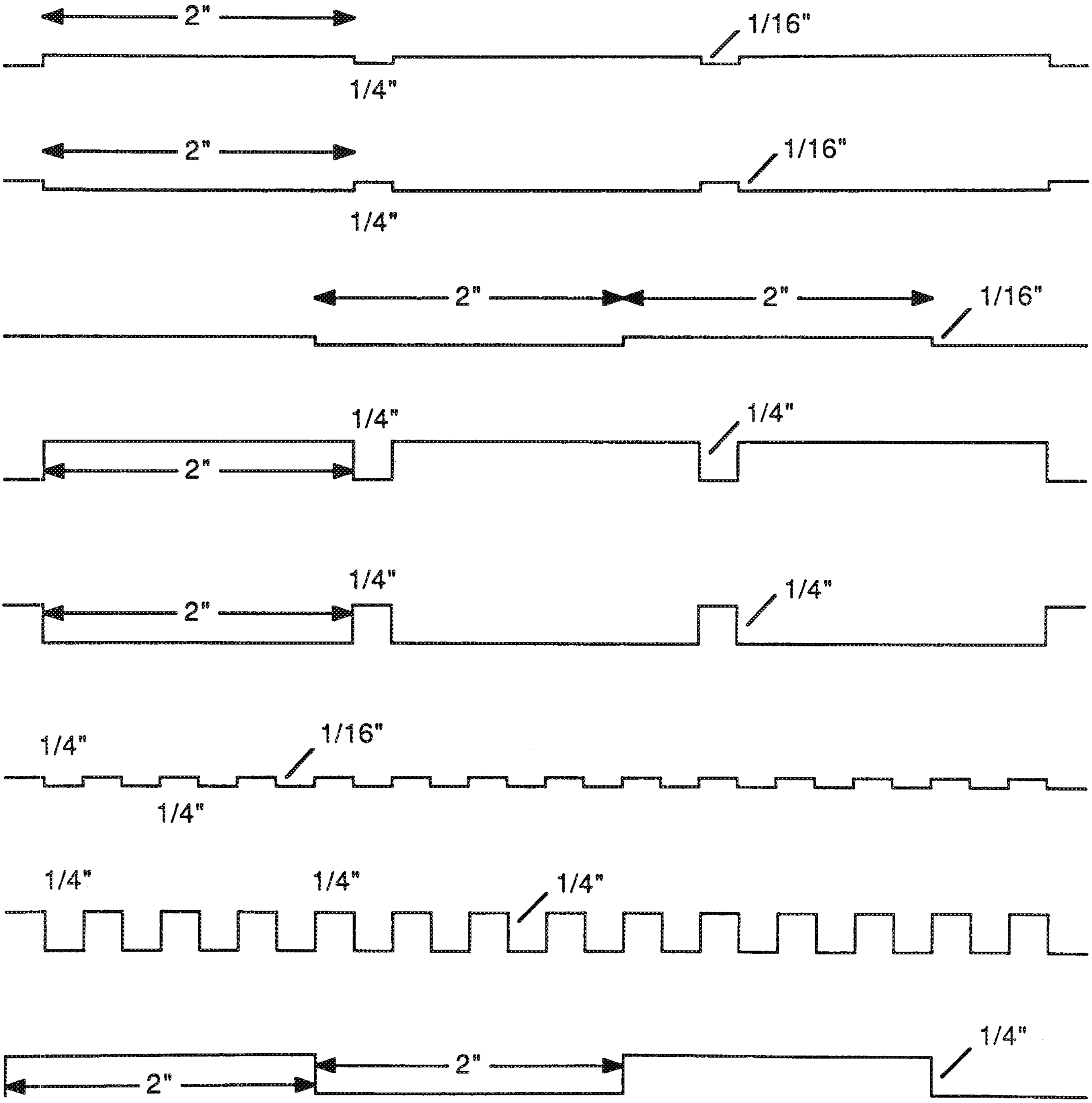


FIG. 3-2. CROSS-SECTIONS OF SURFACES FOUND BY OTHER RESEARCHERS TO BE LOW IN DETECTABILITY

of PVC "T" molding with the shaft embedded in parallel grooves in plywood. The protruding dome-shaped top of a cross-section of the molding was 3/4 inch wide and 3/16 inch high. Strips of the "T" molding were embedded in the plywood so that they were 2 inches apart, center to center (See Fig 3-3).

3.1.1.3 Procedure - Participants were told that in the experiment they would be walking independently on a large platform having four surface materials which might be used as basic platform surfaces, and four other materials which might be used as tactile warnings near a platform edge. They were then guided over the experimental platform so that they approached each material from a direction and/or material other than one which would be used during the experiment. (For example, where possible, they were guided directly from one potential warning to another rather than from a base surface to a warning.)

The following procedure was then described to participants. In the experiment, participants were placed at a random distance from a potential warning (varying from 4 feet to 12 feet), with the warning directly in front of them. The experimenter, who was always 12 feet in front of the participant, then gave a verbal cue, "Come toward me ", which was both a starting signal and an indicator of direction. If subjects veered, the verbal cue was repeated. Participants were asked to stop and remain still when they detected a surface change by either cane or foot. The experimenter recorded the number of cane contacts and the number of foot contacts which the traveller made with the warning before coming to a stop. The distance of the traveller's leading toe was then measured from the beginning of the warning surface, and the traveller was asked whether he or she was alerted to the change primarily by cane information, foot information, or a combination of both.

Since sound clues might frequently be masked by ambient noise in the rail rapid transit environment, it was desired to minimize the likelihood of participants detecting changes in surfaces on the basis of sound. Therefore, a tape recording made in Park Street Station (MBTA-Boston) was played continuously at an average volume of 80 dB. Pilot testing indicated that in some trials, some warning might still be detected by sound; therefore, in addition to interfering with the use of auditory cues by masking, participants wore earmuffs which attenuated the sound received by approximately 20dB. Participants were questioned throughout the experimental procedure about the clue/s used for detecting changes. Primary reliance was on texture changes for detecting all surfaces, and secondary reliance was on changes in cane vibration or resiliency under foot. Auditory information was rarely a factor.

Order of presentation as well as distance from each warning were randomized across all warnings and all subjects.

Following the performance portion of the experiment, participants were asked to rate each

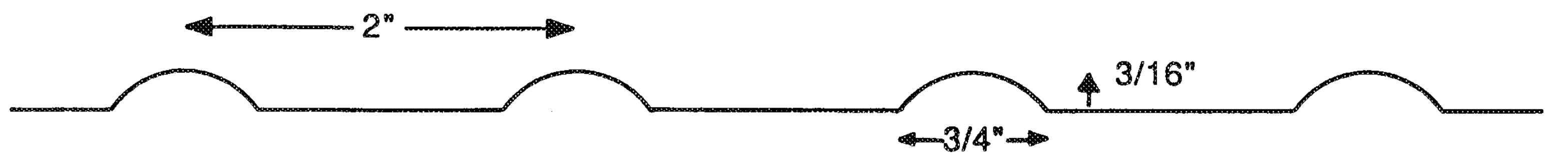


FIG. 3-3. CROSS-SECTION OF "CORDUROY"

of the four warnings for ease of detection on a four point Likert scale, where one = easiest to detect and four = most difficult to detect.

3.1.2 Results

3.1.2.1 Detection Rates Analyzed by Potential Warning Material - When data was collapsed across all subjects and all trials, the rate of detection was greater for "corduroy" than for any other surface. "Corduroy" was detected on 144 of 148 approaches, for a detection rate of 97.3%. For the four approaches on which "corduroy" was not detected, all the travellers were using dog guides (detection rate 36/40 - 90.0%). Detection rate for cane travellers was 100%.

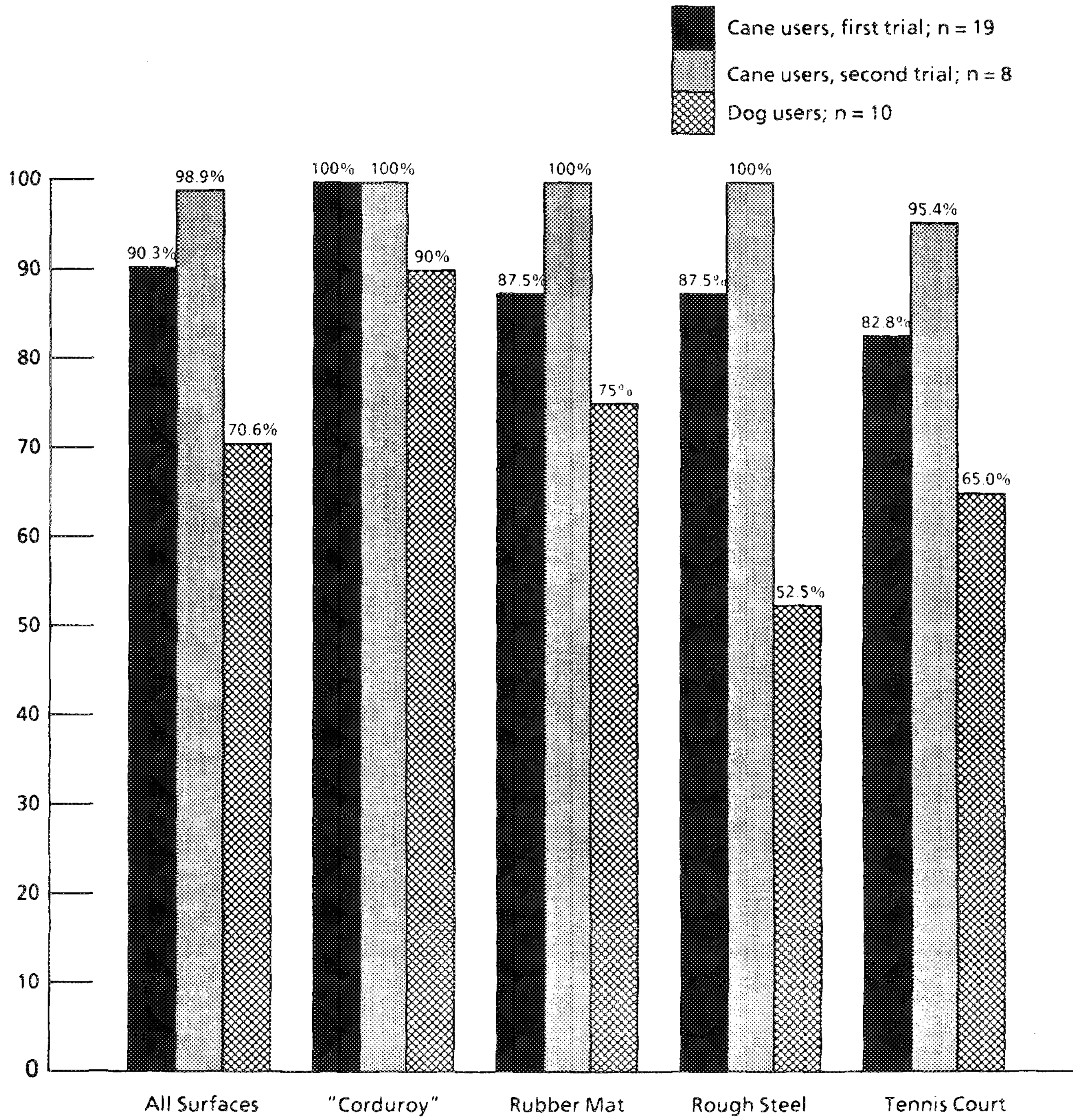
The ribbed rubber mat had the next highest rate of detection when data was collapsed across all subjects and all trials. The rubber mat was detected on 130 of 148 approaches, for a detection rate of 87.8%. Detection rate for first trial cane users was 87.5%, while that for dog users was 75%. Detection rate for cane users on a second trial increased to 100%.

When data was collapsed across all subjects and all trials, rough steel had the next highest detection rate. Steel was detected on 128 of 148 approaches with a detection rate of 83.1%. Of the 25 approaches on which steel was not detected, 19 were by dog users, and six were by first trial cane users. The detection rate for dog users was, therefore, only 52.5%, while that for first trial cane users was 87.5%. Detection rate for second-trial cane travellers was 100%.

When data was collapsed across all subjects and all trials, tennis court surfacing had the lowest rate of detection. This rate was essentially the same as that for steel, however. Tennis court surfacing was detected on 121 of 148 approaches, for a detection rate of 81.8%. Of the 27 approaches on which tennis court surfacing was not detected, 14 were by dog guide users (detection rate 65%) and 11 were first trial cane users (detection rate 82.8%). Detection rate for second-trial cane users increased to 95.4%. Comparative detection rates between surfaces and for various subject breakdowns are presented in Fig. 3-4.

From these results it can be concluded that the corduroy surface had the highest rate of detection. Rubber matting was detected as well as "corduroy" by cane travellers who had practiced. Therefore, it had the best detection rate of the three commercially available warning materials. The detection of steel and tennis court surfacing was less reliable, especially by dog guide users. Cane users had greater success in detecting potential warning materials than dog guide users, and the detection rate of cane users increased with practice.

3.1.2.2 Detection Rates Analyzed by Base Surfaces - An important question addressed in this project was whether it is possible to specify a warning material or materials which is/are detectable when used in association with different platform flooring materials. The previous analysis



Detectability is shown in terms of the percentage of trials on which warnings were detected. The first three bars give the percentages when detection scores for all surfaces are lumped. The following four sets of three bars give the percentages for detection for each surface individually.

FIG. 3-4. DETECTABILITY OF POTENTIAL WARNING MATERIALS: LABORATORY TESTING

indicated there are materials highly detectable in association with all four extreme examples of base surfaces. The data were further analyzed by base surfaces to ascertain whether use of a particular base surface is associated with high or low detection rates for warnings used with that surface.

Collapsing data across all subjects, all trials, and all four warning surfaces, travel from brushed concrete onto all warning surfaces yielded a detection rate of 93.7%. All of the subjects who, when starting on brushed concrete, failed to detect a warning, were dog guide users who were travelling from concrete to either steel or tennis court surfacing. Detection rates were 100% for all subjects and all trials when travel was from concrete to either rubber matting or corduroy.

Collapsing data across all subjects, all trials, and all four warning surfaces, travel from the other three base surfaces, (course aggregate concrete, wood, and Pirelli tile), onto all warnings yielded detection rates which ranged from 86.5% to 83.8%, and which were therefore essentially equal.

3.1.2.3 Mean Stopping Distance - For those trials in which warnings were detected, when the data for stopping distance were examined, it appeared that stopping distances were essentially equal across all potential warning surfaces. For all subjects on all trials, 85% stopped after traversing less than 30 inches of the warning. To reach the 95% level, 42 inches was required.

Of more interest than the cumulative frequency percentages for all subjects on all trials is the discrepancy between stopping distances for cane and dog users and between first and second trial cane users. For first trial cane users, 85% stopped after traversing less than 18 inches while for second trial cane users, only 6 inches of the warning were required to enable 85% to stop. For dog guide users 48 inches were required to enable 85% to stop.

In order for 95% to stop, the following distances were required:

1. First trial cane users - 24 inches
2. Second trial cane users - 18 inches
3. Dog guide users - 48 inches

Thus, while the use of different warnings does not result in different stopping distances, dramatically different distances are required depending on the type of travel aid used, with cane users requiring less of the warning than dog guide users. There appears to be a possibility of practice significantly decreasing the amount of warning distance required by cane travellers. This information is portrayed in Table 3-2.

3.1.2.4 Means ofDetection (cane vs foot) -Travellers using long canes had two possible means of detecting surface changes - the long cane and the foot. Dog guide users, on the other hand, had to rely solely on changes under foot.

TABLE 3-2. STOPPING DISTANCES AND CUMULATIVE FREQUENCIES COLLAPSED ACROSS ALL WARNINGS AND ALL BASE SURFACES

Stopping Distance	Cumulative Frequency - Percentage of Travellers that Stopped by Each Distance			
	1st Trial Cane Users	2nd Trial Cane Users	Dog Guide Users	All Subjects - All Trials
48"	100.0		100.0	100.0
42"	97.8	100.0	83.3	95.0
36"	97.8	99.2	77.2	93.5
30"	97.1	96.8	59.6	88.7
24"	96.1	96.0	43.0	84.3
18"	85.5	93.7	27.2	75.6
12"	78.5	88.9	18.4	67.8
6"	66.7	83.3	2.6	56.8
0"	58.4	75.4	.0	49.7
-6"	47.3	59.5	.0	39.9
-12"	31.9	45.2	.0	28.2
-18"	13.6	24.6	.0	13.4
-24"	2.9	10.3	.0	4.2
-30"	1.1	1.6	.0	1.0
-36"	.7	.0	.0	.4

*These data are only for trials in which warnings were detected.

All cane users were asked, after each detection, whether they detected change by cane, under foot, or by both means combined. The data for first trial cane users were analyzed to determine whether the nature of the warning material interacted with means of detection. It did not.

It is interesting to note, first trial cane users subjectively reported that they detected warnings with the cane 204 of 263 times, (77.6%), and 35 times (13.3%) under foot, and 24 times (9.1%) using a combination of cane and foot information.

3.1.2.5 Subjective Rating of Ease of Detection - All subjects were asked, after they completed the experimental procedure, to rate the warnings for ease of detection on a four point Likert Scale, with one being the easiest to detect. Mean scores were obtained for each warning, with the following mean subjective ease of detection ratings:

1. Corduroy - 1.2
2. Rubber Matting - 2.0
3. Steel - 3.3
4. Tennis Court Surfacing -3.5

3.1.3 Summary and Discussion

In analyzing the data both by detection rate and subjective rating of ease of detection, the "corduroy" surface performed best. It was the only surface detected by more than 75% of dog users, and 100 % of cane users. The mean subjective detectability rating (one = easiest to detect) was 1.2.

It would be premature, however, to recommend the use of the tested "corduroy" because it was the only surface tested which consisted of domed ridges. A better spacing might be greater or less than the 2 inches tested. The best width might differ from the 3/4 inch tested, and the best height might differ from the 3/16 inch tested. Further, data should be obtained on detectability of this pattern when it is made in a material or materials suitable for transit architecture. Also, although the "corduroy" used in this experiment was subjectively judged by physically impaired persons, including those in wheelchairs, to have minimal effect on their travel when used in a relatively narrow strip at a platform edge, no empirical data was obtained. Thus, although a surface has been found which is detected better than any tested commercially available surface, especially by dog guide users, these three important questions should be answered by empirical research before this surface is recommended as a tactile warning.

1. What are the optimim dimensions of the surface?
2. In what material or materials suitable for transit architecture can this surface be manufactured?
3. What are the effects of this surface on the travel of physically impaired persons?

In addition, cost and durability studies will need to be conducted.

Of the three currently available potential warning surfaces which were tested, ribbed rubber matting performed better than either rough steel plate or a tennis court surface. It was detected by 100% of cane users in the second trial, and by 75% of dog guide users. The mean subjective detectability rating was 2.0.

Although there were differences in detection rates, it is important to note that all four potential warnings were detected on more than 80% of trials by cane users in an unpracticed situation, and that in a second trial by cane users, all four were detected on more than 95% of trials; thus, all four are highly detectable, and detection of all the potential warnings involved in this study appears to be a relatively easy skill for cane users to learn.

Not one of the four basic platform materials, selected as representative of the extreme differences in platform materials currently in use, was associated with poor detection rates for warnings. Smooth concrete was associated with particularly high detection rates, however.

The choice of tactile warning material does not appear to interact with stopping distance (measured as the distance from the tip of the leading toe to the edge of the warning adjoining the base surface in which the subject started). This finding is in agreement with that of Templer, et al. (1982), and the actual stopping distances are similar when comparing the results of Templer, et al. (1982) with our results for all subjects and all trials. That is, on approximately 85% of subject trials, subjects stopped after traversing 24 inches or less of the warning. However, it is important to note that considerably greater distances were required by dog guide users than by cane users.

3.1.4 Implications for Rail Rapid Transit

Of the three commercially available potential tactile warning materials involved in this experiment, all offer the potential of being highly detectable by long cane users. They all appear to be detectable when used in association with a variety of basic platform surface materials, and thus to have promise for consistent use throughout a system in which platform surfaces vary.

One possible problem in the use of these commercially available surfaces as tactile warnings is that they are commonly used in other contexts; thus, blind travellers might be less likely to respond to them as warnings than to a surface which is reserved for use as a warning (or which was at least less common in the environment).

The superior performance of the prototype "corduroy" surface as a tactile warning indicates that a surface or material may yet be located or created which results in much greater detection rates than any commerically available product which has been empirically tested for use as a tactile warning. Research and development in this area should be encouraged.

Since none of the four platform flooring surface extremes used in this experiment were associated with particularly poor detection rates for warnings, it seems likely that properties of one or a group of tactile warning materials can be specified for use in transit architecture which will be highly detectable when used in conjunction with all common platform flooring materials. The superior performance of concrete indicates that laboratory detection rates based purely on comparison with concrete may be unrealistically high. Future research should consider at least selected other base surfaces as well as concrete, where the objective is to identify tactile warnings detectable when used with varied platform flooring materials.

A highly detectable tactile warning, 24 inches wide and placed at the edge of the platform, should be sufficient to alert approximately 85% of long cane users who do not have peripheral neuropathy or cold feet to the presence of the drop in ample time for them to stop. Reduced tactile sensitivity due to three common causes makes it unrealistic to hope for a tactile warning which all blind travellers will detect and respond to. These causes are diabetes (a common cause of blindness in older persons), low temperatures, and the wearing of heavy gloves or boots.

A tactile warning should function as a back-up warning. Blind persons taught to travel with the aid of long canes learn to respond to drops detected by the cane. Persons who travel with the aid of dog guides normally rely on their dogs to stop them before a drop is encountered.

Tactile warnings can reduce the occurance of falls from the platform, but even the most detectable tactile warnings, consistently placed and well maintained, cannot prevent blind travellers from falling from the platform.

Training in the detection of tactile warnings, coupled with the consistent use of highly detectable tactile warnings in transit architecture, seems likely to greatly improve the relative safety of blind travellers in the rail rapid transit environment.

4.0 IN-TRANSIT RESEARCH

4.1 SITE SELECTION

The Bay Area Rapid Transit Authority (BART), San Francisco, which is committed to the installation of a tactually identifiable edge detection system along the full length of the edges of all its high level platforms, cooperated as the in-transit test site for validation of the detectability of a tactile warning material under normal transit conditions. BART, under the guidance of Ralph Weule, Director of Safety, retrofitted three stations with the highly discriminable "corduroy" in two commercially feasible materials. All three stations had center platforms. One edge of each station platform was fitted with a PVC "corduroy" and the other edge was fitted with an epoxy "corduroy". These materials were applied the full length of platforms, and extended away from the platform edges for a width of 24 inches. This width was based on the results of laboratory research (See Section 3.0) in which blind participants travelling with long canes detected potential warning materials. On 85% of trials, blind participants stopped after traversing no more than 24 inches of the potential warning material. (See Weule, R.S., 1986, for technical specifications of the materials installed for testing at BART.)

Since the experiment was to test detectability as well as durability in the greatest possible variety of potential situations within BART, the three stations selected for testing represented the following composite criteria:

1. Indoor and outdoor
2. Underground and above ground
3. High usage and moderate usage
4. High ambient noise and moderate ambient noise
5. Very smooth base flooring (terrazo), moderately smooth base flooring (brushed concrete), and relatively rough base flooring (brick pavers).

4.2 EXPERIMENT DEVELOPMENT

Tests for the detectability by blind travellers of each surface in each station were planned by Bentzen and Peck in a repeated measures complete factorial design. Tests for the ability of wheelchair users and other ambulatory impaired persons to negotiate the surfaces were also designed. The design and conduct of testing was supported by technical assistance from BART.

4.2.1 Pathfinder Warning Tile

When testing plans and installation of the "corduroy" were nearly complete, another potential warning material, Pathfinder Warning Tile, was located. This material was anticipated to be highly detectable because its surface texture had similar critical characteristics to the "corduroy" This tile has a texture of .197 inches high, .453 inch diameter bumps 2.36 inches apart, center to center (see Fig. 4-1). These tiles had been applied some months earlier on the corners of a busy intersection in Sacramento. While no data on detectability had been obtained by Bentzen and Peck or by involved persons in Sacramento, BART was interested in comparing the detectability of the Pathfinder Warning Tile to the two "corduroy" materials. Bentzen and Peck anticipated detectability might be as good as for "corduroy" because of the similarity in critical dimensions and the similarity in cross section, and agreed to incorporate the tile into the testing. As all three test stations were already fully retrofitted with "corduroy", and since only 100 feet of tile could be obtained for prototype installation, the tile was applied along only 100 feet of one platform of one indoor, underground, moderate use, moderately noisy station with a terrazo floor. All of the same tests were planned for the tile as for the two "corduroys", but because of the limited application a complete factorial design comparing Pathfinder Warning Tile with "corduroy" was not possible. The implications of this design weakness will be considered under Section 4.4.

4.2.2 <u>In-Transit Testing Questions</u>

In-transit testing in the BART system was designed to address the following questions:

1. Is a warning texture ("corduroy") which was highly detectable to blind travellers in laboratory testing, also highly detectable in actual rail rapid transit conditions, with varied flooring materials, indoors and outdoors, underground and above ground, in both high and moderate usage stations and in stations with both high and moderate ambient noise?
2. Are the "corduroys" produced by two commercial materials and processes equally detectable to blind travellers under all conditions?
3. Does another material (Pathfinder Warning Tile) exist which is also highly detectable to blind travellers in a limited set of actual rail rapid transit conditions?
4. Are the two "corduroys" and the Pathfinder Warning Tile equally detectable under foot?
5. Are the two "corduroys" and the Pathfinder Warning Tile equally detectable to travellers using long canes?
6. Are the "corduroys" and the Pathfinder Warning Tile equally detectable to travellers using dog guides?
7. Is a width of 24 inches from the platform edge sufficient to enable stopping safely before contacting the platform edge on at least 90% of trials regardless of whether detection is under foot or by long cane?
8. Is it difficult or impossible for users of electric or manual wheelchairs, or other ambulatory impaired persons to travel on either "corduroy" or Pathfinder Warning Tile?

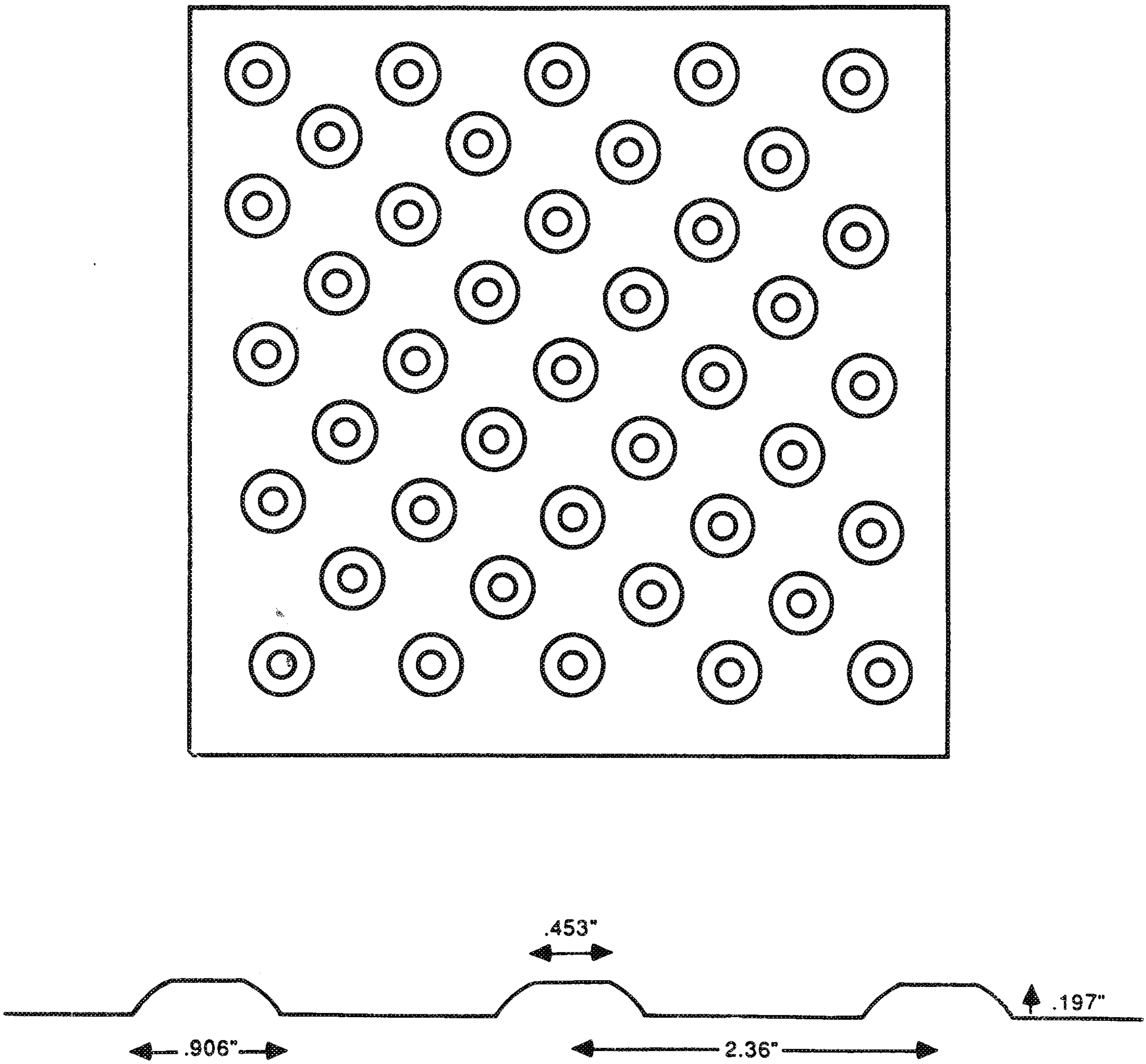


FIG. 4-1. PATTERN AND PROFILE OF PATHFINDER TILE

9. Do users of electric or manual wheelchairs or other ambulatory-impaired persons anticipate that their use of BART would be so impaired by installation of an edge detection system that its installation would be considered an architectural barrier for them?

4.3 METHOD

4.3.1 Subjects

Thirty totally blind travellers participated in experiments to determine the detectability of the three edge detection systems; 19 used long canes as travel aids, and 11 used dog guides. Participants were recruited from the greater San Francisco area by members of the BART Handicapped Advisory Committee, and by persons responsible for conducting performance tests for blind persons. Participants are described by age, sex and travel aid in Table 4-1.

Twenty-four ambulatory-impaired travellers participated in experiments to determine the effects of edge detection systems on their travel. Ten participants used an electric wheelchair, four used a manual wheelchair, and ten used various walking aids or had gait problems. This last group is referred to as "other ambulatory impaired." Participants were recruited from the greater San Francisco area by members of the BART Handicapped Advisory Committee and by the person responsible for conducting the tests for ambulatory-impaired persons. Participants are described by age and sex in Table 4-2. An attempt was made to keep the three groups equivalent in terms of age and sex distribution, but there were difficulties in recruiting willing participants. The "other ambulatory-impaired" group was much older (range and mean) than the other two groups, and , therefore, might have been expected to have some difficulties attributable to other aging processes instead of, or in addition to, their ambulation problems.

4.3.2 Materials

The three BART stations in which the two "corduroys" were installed were Berkeley, Montgomery and Rockridge. The tile was installed in Lake Merritt. Characteristics of these stations are summarized in Table 4-3.

TABLE 4-1. BLIND PARTICIPANTS

AGE		SEX		TRAVEL AID	
		M	F	CANE	DOG GUIDE
1.	17		X	X	
2.	19		X	X	
3.	19	X		X	
4.	19	X		X	
5.	20	X		X	
6.	20		X	X	
7.	21	X		X	
8.	22	X		X	
9.	23	X		X	
10.	24	X		X	
11.	25	X			X
12.	25		X		X
13.	27	X		X	
14.	27		X		X
15.	28		X		X
16.	29	X			X
17.	30	X		X	
18.	30		X		X
19.	31		X		X
20.	31	X			X
21.	32	X		X	
22.	32	X		X	
23.	33	X		X	
24.	35	X		X	
25.	37		X		X
26.	38	X		X	
27.	39	X			X
28.	40	X		X	
29.	41	X			X
30.	51	X		X	
TOTAL MEAN AGE - 28.8		21	9	19	11

<u>OVERALL:</u>

AGE RANGE	17-51

<u>CANE USERS:</u>

AGE RANGE	17-51
MEAN AGE	26.1
MALES	16
FEMALES	3

<u>DOG GUIDE USERS:</u>

AGE RANGE	25-41
MEAN AGE	31.18
MALES	5
FEMALES	6

TABLE 4-2. OTHER PARTICIPANTS

AGE		SEX		WHEELCHAIR		OTHER AMBULATORY IMPAIRED
		M	F	BATTERY OPERATED	MANUAL	
1.	21	X		X		
2.	25	X			X	
3.	25		X	X		
4.	27	X		X		
5.	28	X		X		
6.	34	X		X		
7.	37		X		X	
8.	37		X	X		
9.	39		X		X	
10.	39	X		X		
11.	42	X		X		
12.	42		X	X		
13.	42	X				X
14.	42		X			X
15.	45		X		X	
16.	62	X				X
17.	69	X				X
18.	78	X				X
19.	78	X				X
20.	78		X			X
21.	81		X			X
22.	84		X			X
TOTAL MEAN AGE - 46.75		12	10	9	4	9

OVERALL:
AGE RANGE 21-84

WHEELCHAIR USERS:		BATTERY OPERATED CHAIR USERS:		MANUAL CHAIR USERS:		OTHER ABULATORY IMPAIRED:	
TOTAL	13	TOTAL	9	TOTAL	4	TOTAL	4
AGE RANGE	21-45	AGE RANGE	21-42	AGE RANGE	25-45	AGE RANGE	42-84
MEAN AGE	33.29	MEAN AGE	32	MEAN AGE	36.5	MEAN AGE	65.6
MALES	9	MALES	8	MALES	1	MALES	5
FEMALES	4	FEMALES	1	FEMALES	3	FEMALES	4

Table 4-3: CHARACTERISTICS OF TEST STATIONS

	Floor	Elevation	Indoor/Outdoor	Usage	Noise
STATIONS FOR "CORDUROY"					
Berkeley	Terrazo	Underground	Indoor	High	Medium
Montgomery	Brick Pavers	Underground	Indoor	High	Medium
Rockridge	Brushed Concrete	Above ground	Outdoor	Medium	High
STATION FOR PATHFINDER WARNING TILE					
Lake Merritt	Terrazo	Underground	Indoor	Medium	Medium

In order to retrofit the edges of the platforms with the "corduroy", existing platform edges were routed out in parallel grooves 2 inches apart, center to center, for a total width of 24 inches from the platform edge using a router especially developed for the purpose. In each of 3 stations one "corduroy" was installed on one platform edge which consisted of epoxy polyaggregate. Another "corduroy" was installed on the remaining platform edge which consisted of PVC moldingin each station.

The surface of the PVC was smooth, and shortly after installation it was noticed it could be a slipping hazard. The PVC strips were then promptly coated with a non-slip finish consisting of sand in epoxy.

Pathfinder Warning Tiles were installed for a 24 inch width along 100 feet of one platform at Lake Merritt Station.

4.3.3 Procedure for Blind Participants

A tactile warning edge detection system to increase the safety of visually impaired users of rail rapid transit should be conceived of as a kind of fail-safe secondary warning alerting travellers that a downward level drop is near. Long cane users are normally alerted to the presence of an impending drop by the failure of the cane tip to contact a surface at the level on which they are travelling. They then can take no more than one step before going beyond the edge of the drop. Dog guide users are normally alerted to the presence of an impending drop by the stopping of their guides. Thus, both long cane and dog guide users have techniques to inform them about the location of drops when they are alert, unconfused, and using good technique. The number of falls blind persons experience from raised platforms is evidence that these techniques are far from fail-safe.

A fail-safe secondary warning useable by all blind travellers must be highly detectable under foot, as dog guide users do not have cane tip information available, and long cane users who have accidents are those who do not obtain or respond to cane tip information. A primary concern of in-transit testing, therefore, was that the tests yield information about detectability under foot; thus, the procedure for this experiment included not only having each blind traveller approach the warning with his or her conventional aid for independent travel, (i.e. cane or dog guide) but also having each traveller approach the warning with a human guide. The inclusion of this human guide condition (not used previously in this type of research by either these researchers or others) enabled collection of performance data on detection of warnings by all blind participants based solely on under-foot information.

Experimenters first familiarized participants with the feel of the warning materials underfoot. Each participant subsequently approached each platform edge equipped with "corduroy" (six edges) one time with a human guide. Angle of approach was perpendicular to the platform edge, diagonal (35 degrees right or left), or nearly parallel to the platform edge (10 degrees right or left). Approach distance varied from 7 to 30 feet. Angle and approach distances were initially counterbalanced across platforms and between participants so that all platforms were intended to be approached an equal number of times from each distance and angle. The counterbalancing scheme could not be perfectly implemented due to the difficulties of coordinating visits to multiple stations by multiple participants, when all participants did not arrive when and where they were expected. Thus, precise analysis of the effects of approach angle and distance could not be carried out. The counterbalancing was, nonetheless, complete enough to achieve its primary purpose of ruling out the effects of anticipation. Order of administration of platforms within stations (i.e. PVC "corduroy" vs. epoxy "corduroy") was counterbalanced across and within participants, and order of administration of stations (i.e. Berkeley, Montgomery, and Rockridge) was also counterbalanced.

Each participant was also guided three times to the Pathfinder Warning Tile at Lake Merritt Station. Approach angle and distance were counterbalanced as for the "corduroys". Thus, each blind participant approached each "corduroy" three times (once in each of three stations), and the Pathfinder Warning Tile three times (all in one station).

Each participant who customarily travels with a long cane (n=19) also used the long cane when approaching both "corduroys" in one of three stations three times (from three different approach angles and distances). The three stations having "corduroy" were used an approximately equal number of times for this long cane testing. In addition, each of these participants approached the Pathfinder Warning Tile three times with the long cane; thus, each of the three surfaces (two "corduroys" plus Pathfinder Warning Tile) was approached three times by each long cane user.

Each participant who customarily travels with a dog guide (n=11) also used the dog guide one time when approaching each of the three tactile warning surfaces. Choice of the station for approaching the "corduroys" was randomized across participants. In all tests of blind participants, both the order of administration of tasks (i.e. human, long cane, or dog guide) and the order of warnings (i.e. PVC "corduroy,"epoxy "corduroy,"and Pathfinder Warning Tile) were randomized to rule out systematic practice effects. For each test, participants were instructed to stop as soon as a different surface was detected (by whatever means). Experimenters then measured the distance from the closest part of the closest foot to the edge of the platform.

All trials for all blind participants were conducted when no train was in the station. A portable wire mesh barrier, moved and stabilized by BART personnel, was placed at the very edge of each platform for each trial to insure that no participant could fall to the trackbed.

4.3.4 Procedure for Wheelchair Participants

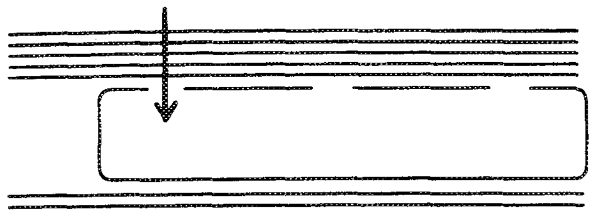
Participants using wheelchairs (battery operated chairs n=10; manual chairs n=4) were tested on six tasks involving the manipulation of wheelchairs on the edge detection system. All wheelchair tests on "corduroy" were conducted in Berkeley Station, which has a terrazzo floor, because members of the BART Handicapped Advisory Committee anticipated that difficulties would be greatest where the floor was the smoothest. Therefore, the test was carried out in a "worst case" situation. Wheelchair tests on "corduroy" were performed on the epoxy surface. The results should be generalizable to the PVC "corduroy" or any other "corduroy" with similar dimensions and friction characteristics. In addition, all six tests were performed on the Pathfinder Warning Tile installed in juxtaposition with terrazzo at Lake Merritt Station.

The six tasks participants performed are listed in Figure 4-2. The dependent measure was whether a subject was "able to perform" or "unable to perform" each task. Following the performance of all six tasks on each surface, participants were asked to respond to a brief survey (Figure 4-3) in which the effect of the tactile warning on their use of BART was rated, and in which they had the opportunity to give suggestions for techniques or strategies for minimizing any adverse effects the tactile warnings had on their travel.

4.3.5 Procedure for Other Ambulatory Impaired Participants

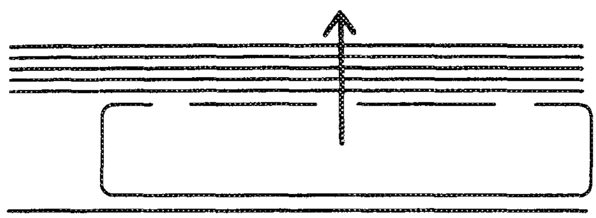
Participants (n=10) who used various walking aids such as canes, crutches, or walkers, or with gait problems, performed tasks 1,2,4, and 6 shown in Figure 4-2, on "corduroy" and on Pathfinder Warning Tile. They subsequently responded to the survey.

Task 1



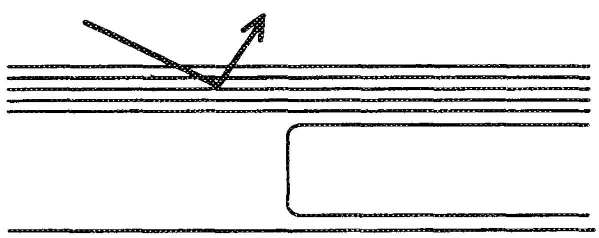
Start on terrazzo. Move straight ahead, across detection system, onto train.

Task 2



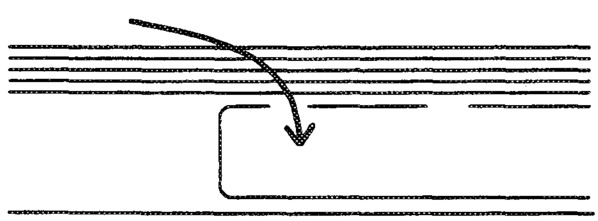
Start on train. Move straight ahead, across detection system, onto terrazzo.

Task 3



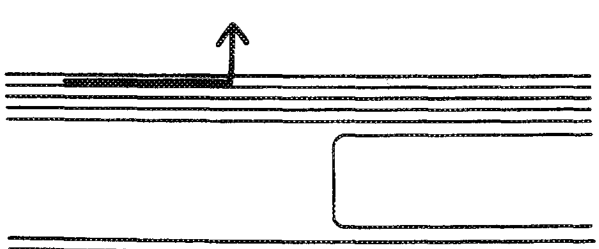
Start on terrazzo, facing edge at 35°. Move straight ahead, halfway onto warning track with one wheel, then turn 90° to return to terrazzo.

Task 4



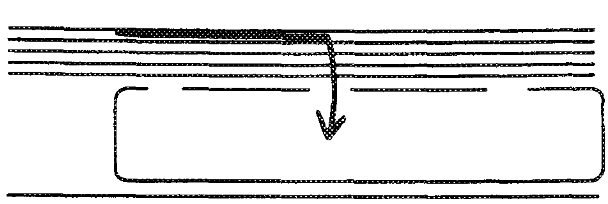
Start as in task 3, but turn to enter vehicle.

Task 5



Start with one wheel in the space between the two detection ridges farthest from platform edge. Move parallel to edge, then turn left to return to terrazzo.

Task 6



Start as in task 5, but turn to enter vehicle.

FIG. 4-2. TASKS FOR WHEELCHAIR USERS

EFFECTS OF EDGE DETECTION SYSTEM ON TRAVEL OF NON-VISUALLY IMPAIRED TRAVELLERS

1. To what extent do you think your travel on BART would be affected by the presence of an edge detection system?
   a. ____ not affected
   b. ____ insignificantly affected
   c. ____ moderately impaired
   d. ____ seriously impaired

If (c) or (d) please indicate why____
____

2. Were any of the six experimental tasks particularly difficult for you?
   ____ yes
   ____ no

   If yes, which condition or conditions were particularly difficult?____________________
   ____
   ____

   Describe the nature of the difficulty____
   ____
   ____

3. Were there any particular techniques or strategies which you used or would use in any of these tasks?____
____

FIG. 4-3. BART TACTILE WARNING SURVEY

4.4 RESULTS AND DISCUSSION OF TESTING OF BLIND PARTICIPANTS

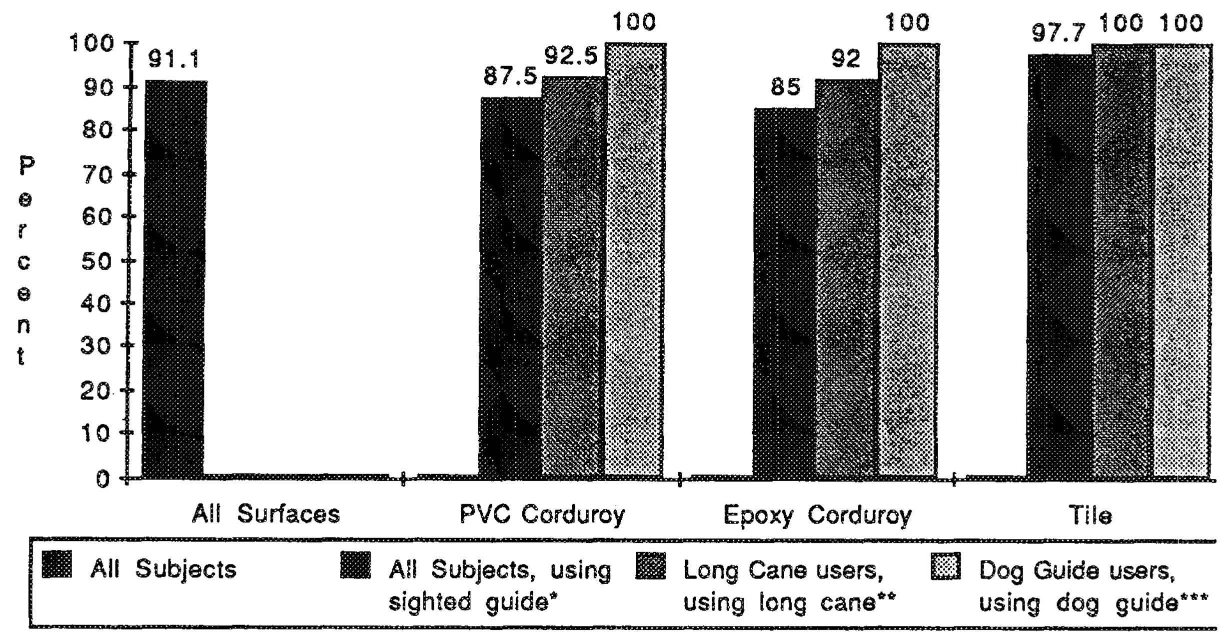
When collapsed across warning surfaces, participants detected and were able to stop within the available 24 inches of warning surface on 91.1% of 270 trials using a sighted guide (See Figure 4-4). However, analysis by chi square revealed a significant difference in the detection rate between both "corduroys" and the Pathfinder Warning Tile (chi-square = 8.42, df = 2, $p < .01$), with the tile being more detectable when approached using a human guide.

When approached using a long cane, no significant differences in detectability of the three warnings existed, although the direction of difference was the same as for the sighted guide condition; i.e. Pathfinder Warning Tile was detected better than either "corduroy."

The data for approaches using dog guides are misleading (100% for each surface). The dog guides, while not appearing to stop because of the warning, did stop before (or veer away from) the barrier which prevented an accidental fall to the trackbed. Completion of these tasks by travellers using dog guides indicates such travellers will normally find any of the warnings detectable underfoot, but the 100% rate is probably an artifact of the testing situation and the response of the dog guide to the test situation. No better, ecologically valid, safe measure of detectability of warning surfaces by dog guide users in the transit envronment could be devised by these investigators or others with whom they consulted.

Cumulative frequencies for stopping distances for the 246 human guide trials on which participants detected and stopped on the warning surface before contacting the barrier (a stopping distance of at least 3 inches from the platform edge) are shown in Table 4-4. There were no significant differences in stopping distances for the three surfaces.

Although in the context of this experiment the Pathfinder Warning Tile was significantly more detectable than either "corduroy" surface, the tile was placed on a single platform which optimized the likelihood of detection in several ways. First, the single platform to which the tile was applied consisted of terrazzo, a material which differed markedly from the tile in density as well as in surface texture. Second, the station in which the tile was installed had moderate usage and moderate ambient noise. Stations in which the "corduroys" were located included those with high usage and high ambient noise, and the "corduroys" did not contrast in resiliency with the base platform material. Therefore, it can only be concluded that in this optimal environment for Pathfinder Warning Tile it was detected more frequently than either "corduroy" which was installed in less ideal environments. It is not known whether Pathfinder Warning Tile would be more discriminable than "corduroy" in other environments.



* (subjects = 30; trials = 90 for each surface) All subjects experienced 3 sighted guide trials on each surface. For each subject, 1 PVC and 1 Epoxy trial were conducted in each of 3 stations, Berkeley, Montgomery, or Rockridge; 3 tile trials were conducted in Lake Merritt station.

** (subjects = 19; trials = 57 for each surface) Long Cane users experienced 3 trials on each surface. For each subject, PVC and Epoxy trials were in 1 of 3 stations, Berkeley, Montgomery, or Rockridge. All tile trials were in Lake Merritt station.

*** (subjects = 11; trials = 11) Dog guide users experienced 1 trial on each surface. For each subject PVC and Epoxy trials were in 1 of 3 stations, Berkeley, Montgomery, or Rockridge. All tile trials were in Lake Merritt station.

Note: Of participants using a long cane who detected the warnings, the following percentages detected the warning using cane tip information only (i.e. they stopped before stepping on the warning surface): PVC 87.8%, Epoxy 90%, Tile 96%

FIG. 4-4. DETECTABILITY OF POTENTIAL WARNING MATERIALS: IN-TRANSIT TESTING

TABLE 4-4. STOPPING DISTANCES BY CUMULATIVE FREQUENCIES* SIGHTED GUIDE TRIALS: ALL WARNINGS

STOPPING DISTANCE **	CUMULATIVE PERCENTAGE OF TRIALS ON WHICH SUBJECTS STOPPED BY THE GIVEN DISTANCE
21"	100.0%
20"	99.2%
19"	97.6%
18"	95.9%
17"	93.4%
16"	90.4%
15"	87.9%
14"	85.4%
13"	76.5%
12"	68.9%
11"	59.6%
10"	50.7%
9"	42.7%
8"	35.1%
7"	27.9%
6"	19.5%
5"	14.0%
4"	10.6%
3"	3.4%
2"	2.1%
1"	.4%

* Data do not include 24 trials on which participants contacted the barrier. On those trials, paticipants were considered as not detecting the warning. Some might have stopped if the wire mesh barrier had not occupied the last 3 inches of the warning and if the warning had been deeper than 24 inches.

** Stopping distance is indicated as the distance of the leading foot from the beginning of a warning, where it adjoins the base surface 24 inches away from the platform edge. The maximum distance that could actually be transversed was 21 inches because the base of the wire mesh barrier intruded 3 inches into the warning. Thus, in the test situation, only 21 inches of the warning were actully available rather than 24 inches.

4.5 RESULTS AND DISCUSSION OF TESTING BY PARTICIPANTS WITH AMBULATION PROBLEMS

All participants were able to perform all experimental tasks on both the tile and "corduroy" surfaces regardless of whether they used electric or manual wheelchairs or walked with difficulty. Results of subjective judgment on the effect of edge detection systems on travel were subjected to descriptive analysis, as is appropriate for this level of data. The results are summarized in Table 4-5.

No participant anticipated that either surface would seriously impair his or her travel on BART; however, seven out of nine participants offered the unanticipated responses that one or both surfaces would be helpful in their travel. Eight of the nine "helpful" responses were from participants in the sub-group who walked with difficulty. Six of 10 participants in this group reported that one or both surfaces would be helpful. The two surfaces appear to be equally helpful. Therefore, neither edge detection system would be expected to seriously impair ease of travel for BART riders who use wheelchairs or who walk with difficulty. On the other hand, either edge detection system could be expected to enhance travel for some persons who walk with difficulty.

A total of seven participants judged that one or both surfaces would moderately impair their ease of travel on BART. The two surfaces appear to be equally troublesome. Participants anticipating moderate difficulty came from all three sub-groups.

A total of 20 participants (83.3%) judged that the tile would help, not affect, or would insignificantly affect their travel on BART. A nearly equal total of 21 participants (87.5%) judged that the "corduroy" surface would help, not affect, or insignificantly affect their travel on BART. On the other hand, four participants for tile and three participants for "corduroy" judged that the edge detection system would moderately impair their use of BART.

There is no basis in either performance data or subjective judgment of participants with ambulation problems to prefer one surface over the other. Although a few participants judged a system would moderately impair use of BART, a larger number expected an edge detection system would make their travel easier or safer.

Some participants found one or more tasks more difficult than the others, but they accomplished them all. Individual wheelchair users had some difficulty changing direction on one or both surfaces, but anticipated that in actual use of BART they would plan to enter and exit vehicles in such a way that turning on the edge detection system was not required. Two users of manual chairs who found it difficult to control the direction of their chairs when travelling on the tiles suggested their difficulty would be decreased if the dot pattern on the tiles was altered to align the bumps vertically as well as horizontally and diagonally.

The primary concern of wheelchair users was not the need for particular techniques to

TABLE 4-5. SUBJECTIVE JUDGEMENT OF EFFECT OF EDGE DETECTION SYSTEMS ON TRAVEL*

	SURFACE									
	TILE RESPONSES					CORDUROY RESPONSES				
SUBJECT GROUP	H	NA	IA	MI	SI	H	NA	IA	MI	SI
MOTORIZED CHAIR	0	5	3	2	0	0	5	4	1	0
MANUAL CHAIR	0	0	3	1	0	1	0	2	1	0
OTHER AMBULATORY IMP	5	3	1	1	0	3	5	1	1	0
TOTAL RESPONSES	5	8	7	4	0	4	10	7	3	0
% OF RESPONSES FOR PARTICULAR SURFACE	21	33	29	17	0	17	41	29	12	0

A total of 20/24 Ss, (83.3%) judged that the tile would help, not affect or insignificantly affect their use of BART

A total of 21/24 Ss, (87.5%) judged that the corduroy would help, not affect or insignificantly affect their use of BART

* Subjects were asked:
To what extent do you think your travel on BART would be affected by the presence of the (tile or corduroy) edge detection system?

H - Helpful

NA - Not Affected

IA - Insignificantly Affected

MI - Moderately Impaired

SI - Seriously Impaired

Note: On nine occasions, subjects gave the particularly unanticipated response: The edge detection system was helpful.

negotiate edge detection systems, but for techniques to negotiate the platform-vehicle gap. Eleven of 14 wheelchair users spontaneously mentioned that negotiation of the gap determined how they approached or exited a vehicle. Particular techniques vary depending on chair design (especially diameter of front wheels) and on individual preference. Some persons always enter and exit at 90 degrees to maximize the likelihood that front wheels will be perpendicular to the gap; some enter and exit backwards so the larger (rear) wheels cross the gap before the smaller wheels; and some enter and exit diagonally so that both front wheels will not cross the gap at the same time. No participant found that his or her particular technique for negotiating the gap was incompatible with either edge detection system, although several mentioned greater care would be needed with an edge detection system when moving from the platform to a vehicle.

4.6 SURVEY OF EXPERIMENTERS

Following the completion of data collection, the three orientation and mobility specialists who conducted the experimental sessions were interviewed by telephone so their professional observations could be utilized in interpreting the data.*

When asked whether they perceived a marked advantage to any of the three warning materials, each of the three experimenters reported the Pathfinder Warning Tile was easier for blind participants to detect than the "corduroys."This may have been because the tile was installed only in an environment which optimized the likelihood of its detection. No disadvantages of any of the three warning materials were identified by the experimenters.

When asked whether the width of the warnings seemed appropriate, all three experimenters expressed a preference for wider warnings (30 inches-36 inches). It is certainly possible that on some of the 41 out of 44 trials in which participants using sighted guides or long canes failed to detect the warning or to stop before contacting the barrier, an additional 6 inches-12 inches would have increased the rate of detection. It is also likely that if the final 3 inches of the 24 inch warning had not been covered by the barrier necessary to assure the safety of participants, more participants would have stopped before the platform edge. They would, of course, have stopped extremely close to the platform edge, but the blind traveller's appropriate response to the detection of the warning at any time should be to move to a position of safety off of the warning.

The data may have been slightly ambiguous on some trials in which blind participants echo-located the barrier. On such a trial, the awareness of the presence of the barrier could have alerted a participant to the presence of the warning, causing the participant to stop before contacting the barrier. Such echo-location was reported on six trials. It may have occured on other trials in which blind participants either were not conscious of it or did not report it. To the extent that this

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*Francine Kuizenga, Howard Lauren, Leanne Lauren was a factor, there may have been a few trials on which participants were recorded as having detected the warning when they would not have detected it without the additional presence of the barrier, or on which they would have required a greater width of warning to enable them to stop before reaching the platform edge.

It was difficult to carry out the experimental procedure with persons who used dog guides because the dog guides sometimes veered away from the barrier or stopped because of the barrier, thereby not permitting their owners to readily contact the warning under foot. The three experimenters were asked whether they had observed anything which indicated that dog guide users might not detect the warning in normal travel. No experimenter had observed any indication that dog guide users would not detect the warning.

All three experimenters considered that any of the warning materials, if installed system-wide, would be of some help to visually impaired users of BART. They were asked whether the installation of tactile warnings throughout the system would affect their instruction of blind clients in the use of the BART system. The experimenters responded that they would familiarize clients with the warning, teach them its location and meaning, and instruct them to wait for trains in a position off the warning. One experimenter emphasized he would nonetheless stress detection of the platform edge more than detection of the warning. Another experimenter emphasized she would instruct her students to use a cane technique in which the cane is continuously in contact with the platform surface. This technique is already preferred by many orientation and mobility specialists for use in transit stations with elevated platforms.

4.7 SUMMARY AND CONCLUSIONS

Pathfinder Warning Tile and "corduroy" have been demonstrated to be highly detectable both under foot and by the use of long canes in the rail rapid transit environment by blind travellers. Although in the condition in which subjects used a human guide, the rate of detection for Pathfinder Warning Tile was significantly better than for "corduroy," it must be remembered that human performance data on detection of this tile was limited to one application (BART, Lake Merritt Station) having conditions which optimized the likelihood of detection. The "corduroy" was tested under varied conditions in transit, and previous laboratory testing demonstrated its high detectability when paired with a wide range of other surface materials used in transit architecture. Thus, although Pathfinder Warning Tile was more reliably detected than "corduroy" in the context of this in-transit experiment, it is not certain it would be more detectable, or even as detectable, as "corduroy" in other contexts; particularly because there was a marked difference in resiliency between the tile and the terrazzo with which it was paired, it was possible the detection of the tile was based largely on the difference in resiliency. It is conceivable that, if Pathfinder Warning Tile was installed in juxtaposition with another resilient flooring material, it would no longer be highly detectable; therefore, the data on detectability of the Pathfinder Warning Tile cannot be generalized to contexts in which it is used together with materials more resilient than terrazzo. Further research pairing Pathfinder Warning Tile with other surfaces, particularly surfaces similar in resiliency, is needed before the tile can be recommended for standard use in rail rapid transit stations.

With regard to the width of the warning material from the edge of the platform, on 91.1% of sighted guide trials blind participants detected the warning and stopped after traversing no more than 21 inches of warning. Participants using long canes frequently stopped before stepping on the warning. The installation was 24 inches wide, but the last 3 inches were inaccessable because they were covered by the base of the portable mesh barrier which assured that no participant could fall to the track bed. Thus, a larger proportion of participants might have stopped if the full 24 inch width had been available to them. The three orientation and mobility specialists who conducted the experiment as designed and set up by Bentzen and Peck all suggested a wider warning (30 inches-36 inches) would give a greater measure of safety than the 24 inch width. A wider warning would probably enable more blind travellers to come to a safe stop before the platform edge. The data from this experiment, however, does not indicate how much would be gained from making the warning wider.

No warning can ever be detectable enough and wide enough to prevent all platform edge falls by blind travellers. Peripheral neuropathy, commonly associated with some causes of blindness, makes it difficult or impossible for some blind persons to detect differences in texture or resiliency either under foot or when using long canes. Furthermore, inattention, carelessness, and inebriation, common contributory causes of platform edge falls for all travellers, will not be cured by any change in the physical environment.

Persons who use motorized or manually operated wheelchairs experienced little difficulty on any of the three potential warning materials. None of the materials would make BART less accessable to these travellers. Persons who walk with difficulty, using such aids as canes or crutches, could likewise maneuver on the warnings. Several such participants volunteered they felt more secure on the warning than on the platform itself.

5.0 LABORATORY TESTING OF PATHFINDER WARNING TILE VS. "CORDUROY"

After the high detectability of both corduroy and the Pathfinder Warning Tile Surfaces were determined, a third laboratory test was conducted which compared the discriminability of the surfaces when each was paired with four surfaces representing the major characteristics (smooth vs rough, hard vs resilient) of floor surfaces currently in use in transit stations in the United States:

1. Brushed concrete
2. Coarse aggregate concrete
3. Pirelli Tile
4. Wood

The test platform constructed for the initial laboratory tests was re-used, substituting Pathfinder Warning Tile for the original Kushionkote. (See Fig.3-1.)

5.1 SUBJECTS

Twelve totally blind travellers from eastern Massachusetts participated in performance testing. Seven used long canes, and five used dog guides. Subject characteristics are described in Table 5-1.

5.2 PROCEDURE

The procedure was analogous to that used in testing at BART. Each participant approached each warning from each base flooring surface twice; one time with a human guide, and one time with their conventional aid for independent travel such as a long cane or dog guide.

All warnings were approached perpendicularly from distances varied randomly from three to 11 feet away from the warning. Blind participants stopped as soon as a difference was detected either under foot or by a long cane. When participants were being guided by a person or a dog, they had to rely exclusively on information available under foot. Travellers using long canes typically detected the warning with the cane, in advance of stepping on it.

Stopping distance was measured as the distance of the blind participant's leading toe from the beginning of the warning, as it was approached.

Order of presentation was counterbalanced between guidance systems (human guide, long cane, dog guide) and between combinations of warning and base surface.

5.3 RESULTS

Analysis of variance revealed no significant differences in stopping distances between "corduroy" and Pathfinder Warning Tile attributable to particular combinations of base surface and warning.

TABLE 5-1. BLIND PARTICIPANTS *

AGE	SEX		TRAVEL AID	
	M	F	CANE	DOG GUIDE
33	X		X	
34		X	X	
34		X		X
35	X		X	
36		X		X
36	X			X
37		X	X	
37	X			X
42	X		X	
43	X		X	
44	X		X	
65		X		X

* All participants were totally blind or had no more than light perception.

When travellers were using long canes, the mean stopping distance for all combinations of materials was -4.39 inches, which means when a long cane was used, travellers were typically able to detect the warning and stop before ever stepping on the warning. When travellers were using a human guide, the mean stopping distance for all combinations of materials was 18.12 inches, indicating that travellers typically detected the warning at their first footfall on the warning surface. They often required an additional short step to come to a stop. When travellers used dog guides, the mean stopping distance for allcombinationsof materials was 18.85 inches, indicating that, as for travellers using a human guide, dog guide users typically detected the warning at their first footfall (See Table 5-2).

The over-all detection rate was 99.5%, when collapsed across both warnings, all four base materials, and all three guidance systems. Only one participant on one human guide trial, starting on coarse aggregate concrete, failed to detect and stop within the available 48 inches of the Pathfinder Warning Tile. Thus, there were no significant differences in warning detection which could be attributed to particular combinations of base surfaces and warnings.

The prototype "corduroy" and Pathfinder Warning Tile were equally detectable, therefore, and both were highly detectable when used in association with brushed concrete, coarse aggregate concrete, wood, and Pirelli Tile. A particularly important result is that Pathfinder Warning Tile was highly detectable when juxtaposed with Pirelli Tile, which it resembles in resiliency, sound, and rebound on cane impact. Therefore, Pathfinder Warning Tile appears to be distinctive enough to be detected primarily on the basis of surface texture.

When trying to decide the width of a warning which needs to precede a hazardous drop, it is helpful to examine stopping distances in terms of cumulative frequencies. Cumulative frequencies for stopping distances for the 96 long cane and dog guide trials are presented in Table 5-3. Stopping distances for dog guide trials were always on the the warning because participants on these trials had only under-foot information available to them. On long cane trials, however, only 58.9% of trial participants stopped before stepping on a warning because they detected the warning with the cane. No participant using a long cane required more than 18 inches of a warning in order to come to a full stop; however dog guide users required up to 30 inches of a warning in order to come to a full stop. On 90.6% of cane and dog trials combined, participants stopped within 24 inches, the width of warning used for in-transit testing at BART.

5.4 DISCUSSION AND RECOMMENDATIONS

The prototype "corduroy" and Pathfinder Warning Tile are both highly detectable warning surfaces when used in association with other surfaces representative of those currently in use in rail rapid transit stations in the United States; therefore, either could be used as a tactile warning in transit.

TABLE 5-2. MEAN STOPPING DISTANCES

TRIALS - 95		HUMAN GUIDE TRIALS				
		TOTAL	CEMENT	AGGREGATE	WOOD	RUBBER
CORDUROY	MEAN	16.85	13.08	20.25	16.67	20.42
	SD	(5.96)	(4.66)	(5.14)	(3.39)	(6.26)
PATHFINDER	MEAN	19.38	15.75	20.00	22.00	19.75
	SD	(9.96)	(4.45)	(14.44)	(10.91)	(7.36)

TRIALS - 56		LONG CANE TRIALS				
		TOTAL	CEMENT	AGGREGATE	WOOD	RUBBER
CORDUROY	MEAN	-5.39	-10.57	-2.71	-7.14	-1.14
	SD	(10.32)	(6.40)	(12.47)	(11.25)	(9.60)
PATHFINDER	MEAN	-3.39	-2.57	-0.29	-9	-1.71
	SD	(10.67)	(11.47)	(9.83)	(14.64)	(4.19)

TRIALS - 40		DOG GUIDE TRIAL				
		TOTAL	CEMENT	AGGREGATE	WOOD	RUBBER
CORDUROY	MEAN	19.05	19.40	21.60	12.20	23.00
	SD	(6.16)	(5.68)	(6.07)	(3.83)	(3.16)
PATHFINDER	MEAN	18.65	18.00	19.00	19.40	18.20
	SD	(5.11)	(5.34)	(5.00)	(6.77)	(4.82)

TABLE 5-3. STOPPING DISTANCES BY CUMULATIVE FREQUENCIES: ALL COMBINATIONS OF WARNINGS AND BASE SURFACES

STOPPING DISTANCE*		PERCENTAGE OF TRIALS ON WHICH SUBJECTS IN EACH GROUP STOPPED BY THE GIVEN DISTANCE		
		LONG CANE USERS** TRIALS - 56	DOG GUIDE USERS** TRIALS - 40	CANE & DOG USERS TRIALS - 96
ON WARNING	48"			
	42"			
	36"			
	30"		100.0	100.0
	24"		77.5	90.6
	18"	100.0	60.0	83.3
	12"	98.2	12.5	62.5
	6"	91.1	2.5	54.2
	0"	58.9		34.4
PRECEDING WARNING	-6"	44.6		26.0
	-12"	23.2		13.5
	-18"	14.3		8.3
	-24"	3.6		2.1
	-30"			
	-36"			

* Stopping distance was measured as the distance of the leading toe from the beginning of a warning, where it adjoins a base material.

** Human guide trials are omitted from this table because it is not anticipated that, under normal circumstances, a human guide would allow a blind companion to step off a platform edge. The human guide condition was included in the experiment to be certain that all participants could detect the warnings underfoot if they were not alerted by a long cane, dog guide, or human guide.

Since yellow is accepted as a standard warning color for sighted people because visual consistency in warnings is considered important, it is optimal to adopt a standard warning surface for visually impaired travellers so that a particular surface will always be associated with danger and the need for caution. It is not possible to choose between "corduroy" and a material having the surface characteristics of Pathfinder Warning Tile on the basis of detectability; therefore, other considerations must be examined.

The "corduroy" is a linear surface having a discriminable directionality. It may, therefore, function well as a tactile path to guide visually impaired travellers across open or difficult places. This application of "corduroy" has not yet had rigorous human performance testing, but "corduroy" is suggested to be reserved for this possibility. It is recommended that materials having the surface characteristics of Pathfinder Warning Tile (see Fig. 2) be adopted as standard tactile warnings for use at transit platform edges. The detection of materials like Pathfinder Warning Tile will be maximized in any application by the use of an adjoining material which differs in resiliency as well as in surface characteristics. It is therefore further recommended that warning tiles differ from adjoining materials in resiliency as well as in surface characteristics. In addition, tactile warnings should obviously contrast highly with adjoining materials in color value so that they are visually detectable and interpretable as warnings by sighted travellers.

A width of 24 inches of a tactile warning applied at the edge of the entire length of an elevated transit platforms appears sufficient to enable visually impaired travellers to come to a stop before they reach the platform in more than 90% of approaches when the traveller's usual mobility aid does not provide adequate warning. A wider warning may enable a higher percentage to stop safely. In the most recent laboratory testing, all long cane and dog guide users stopped within 30 inches of the warning; thus, a more cautious approach would be to use a 30 inch warning.

No tactile warning should be less than 24 inches wide. Within any one system, the width should be the same for all applications.

No warning will be absolutely fail-safe. Visually impaired travellers are subject to the same behavioral conditions which cause sighted travellers to fall to the trackbed, such as fatigue, inattention, and inebriation. In addition, either because of cold temperature, heavy footwear and gloves, or a condition called peripheral neuropathy, blind travellers do not always have full sensitivity to changes in texture, vibration, or resiliency.

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